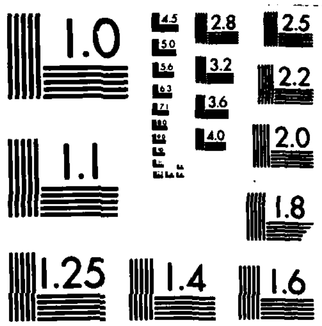
AD-A156 500 RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR(U) AIR COMMAND AND STAFF COLL MAXWELL AFB AL W G ROGERS APR 85 ACSC-85-2215 1/2

UNCLASSIFIED F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

2

AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

RECOGNITION AND CONTROL
OF
LOW LEVEL WIND SHEAR

MAJOR WILLIAM G. ROGERS 85-2215

"insights into tomorrow"

DISCLAIMER

The views and conclusions expressed in this document are those of the author. They are not intended and should not be thought to represent official ideas, attitudes, or policies of any agency of the United States Government. The author has not had special access to official information or ideas and has employed only open-source material available to any writer on this subject.

This document is the property of the United States Government. It is available for distribution to the general public. A loan copy of the document may be obtained from the Air University Interlibrary Loan Service (AUL/LDEX, Maxwell AFB, Alabama, 36112) or the Defense Technical Information Center. Request must include the author's name and complete title of the study.

This document may be reproduced for use in other research reports or educational pursuits contingent upon the following stipulations:

-- Reproduction rights do <u>not</u> extend to any copyrighted material that may be contained in the research report.

-- All reproduced copies must contain the following credit line: "Reprinted by permission of the Air Command and Staff College."

-- All reproduced copies must contain the name(s) of the report's author(s).

-- If format modification is necessary to better serve the user's needs, adjustments may be made to this report--this authorization does <u>not</u> extend to copyrighted information or material. The following statement must accompany the modified document: "Adapted from Air Command and Staff Research Report __(number)__ entitled __(title)__ by __(author)__ ."

-- This notice must be included with any reproduced or adapted portions of this document.

REPORT NUMBER 85-2215

TITLE RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR

AUTHOR(S) MAJOR WILLIAM G. ROGERS, USAF

FACULTY ADVISOR MAJOR JOHN MCGREGOR, ACSC/EDCJ

SPONSOR MAJOR JOHN PLANTIKOW, SIFC/DOI

Submitted to the faculty in partial fulfillment of
requirements for graduation.

AIR COMMAND AND STAFF COLLEGE
AIR UNIVERSITY
MAXWELL AFB, AL 36112

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS N/A
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 85-2215	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION ACSC/EDCC — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Maxwell AFB, AL 36112	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. — PROJECT NO. — TASK NO. — WORK UNIT NO.
11. TITLE (Include Security Classification) RECOGNITION AND CONTROL OF LOW LEVEL	
12. PERSONAL AUTHOR(S) ROGERS, WILLIAM G., MAJOR, USAF	
13a. TYPE OF REPORT — 13b. TIME COVERED FROM ____ TO ____	14. DATE OF REPORT (Yr., Mo., Day) 1985 April — 15. PAGE COUNT 107
16. SUPPLEMENTARY NOTATION ITEM 11: WIND SHEAR	

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is a two hour lesson plan/handbook and slide presentation on low level wind shear. The project was developed for the SAC Instrument Flight Center to be used in their curriculum. The lesson plan is designed to enable SAC instructors to effectively teach other pilots how to understand, recognize, and cope with low level wind shear hazards. The lesson plan addresses the effects, causes, detection, and control of low level wind shear.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL ACSC/EDCC Maxwell AFB AL 36112	22b. TELEPHONE NUMBER (Include Area Code) (205) 293-2483 — 22c. OFFICE SYMBOL

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This document will be utilized as a SAC Instrument Flight Course(SIFC) two hour lesson plan. A slide presentation and handbook will be included as attachments. The slide presentation portion of this project may be obtained by ordering from the Air University Interlibrary Loan Service(AUL/LDEX), Maxwell AFB, AL 36112. (Autovon 875-7223; Commercial 205-293-7223). Requests must include the author's name and complete title of the study.

Requests for quantity reproduction(more than 10 copies) should be addressed to Air Command and Staff College(EDCC), Maxwell AFB, AL 36112. Requests should include a brief explanation of intended use and distribution.

ABOUT THE AUTHOR

Military Experience Related to Research Topic:

1981-1984	Instructor, KC-135: Chief Squadron Training Flight, 42BMW, Loring AFB, ME
1976-1979	Instructor/Evaluator: Chief Squadron Training Flight, KC-135, 19BMW, Robins AFB, GA
1970-1976	Instructor/Evaluator, KC-135: 97BMW, Blytheville AFB, AR

Education:

1981	JD, University of Mississippi
1975	MS, University of Arkansas
1967	BS, University of Southern Miss.

Special Professional Background Experience:

- Academic Instructor, Embry Riddle Aeronautical University, 1983
- Chief, Base Instrument School, 1977-1979
- Graduate, Instrument Pilot Instructor School 1978

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURES

EXECUTIVE SUMMARY

REPORT NUMBER 85-2215

AUTHOR(S) MAJOR WILLIAM G. ROGERS, USAF

TITLE RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR

I. Purpose: To develop a lesson plan for the SAC Instrument Flight Center to teach SAC instructor pilots how to effectively teach the recognition and control of low level wind shear.

II. Need: SAC Regulation 51-37 requires that low level wind shear must be part of the SAC Instrument Flight Center curriculum. To illustrate the magnitude of the low level wind shear(LLWS) problem, from 1962 to 1982, there were 127 U.S. air carrier accidents in which thunderstorms/LLWS hazards were found to be either a cause or a factor. These accidents cost 545 lives and 260 injuries. Additionally, the USAF experienced from 1965 to 1974, 41 probable wind shear/vortex related aircraft accidents with a total price tag of 18 million dollars.

III. Contents: The scissor-like action of two air masses moving in relation to one another can be very hazardous to large, heavy jet aircraft. This phenomena is called low level wind shear when it occurs below 2,000 feet AGL. Factors having a bearing on the effects of LLWS are: aircraft configuration;

CONTINUED

aircraft speed; aerodynamic characteristics; power/weight ratio; engine response time; and the ability of the flight crew to respond. The general effect of LLWS is to modify normal pitch and power requirements used in aircraft ascent and descent profiles. The meteorological phenomena causing LLWS are primarily: (1) thunderstorms; (2) warm and cold fronts; (3) land/sea breezes; (4) occasionally, mountain waves; and (5) less frequently, low level inversions. Recognition and detection of LLWS is very important and is a prerequisite to coping with the hazard. Technology has been developed to assist the air crew in both ground and airborne detection. New radars for ground and airborne use are being developed which will give the air crew warning of the presence of LLWS. However, at present this new technology is still in the developmental stage. Therefore, the air crew must still rely on pilot judgment with inputs from preflight weather briefs, pilot reports, inflight weather service, air traffic control, and aircraft instruments for LLWS detection. The best way to cope with severe LLWS is to avoid it when possible. However, this is not always possible. Using "ground speed" as a reference during approach when wind shear is suspected is important because it insures flying airspeed at all times, even in abrupt wind shear situations. The groundspeed technique is a fairly new concept in airmanship, and may require abrupt power and attitude changes. Also, utilizing minimum drag configurations during departure and approach will aid in acceleration should LLWS be encountered. When encountering microburst conditions near the ground, lowering the nose of the aircraft results in a further, more critical reduction in angle-of-attack, a significant loss of altitude, a degradation of climb performance and ground impact. A more favorable alternative would be to apply maximum thrust while smoothly increasing pitch attitude until the descent is arrested or a stick shaker condition is reached.

IV. Findings: The causes and effects of low level wind shear have been scientifically derived and must be understood by all pilots. Furthermore, research has shown that both ground and airborne low level wind shear forecast and detection equipment is feasible. However, this improved equipment at present is not operational in USAF aircraft.

CONTINUED

V. Conclusions: Until improved forecast and detection equipment for low level wind shear becomes operational, USAF pilots must rely on numerous information sources that are available for detecting low level wind shear encounters. These information sources, coupled with the techniques and procedures available for coping with low level wind shear, should provide the knowledge necessary to successfully cope with this hazard.

Chapter I

INTRODUCTION

STATEMENT OF THE PROBLEM

Can a two hour lesson plan/handbook be developed which will enable SAC instructor pilots to effectively teach other pilots how to understand, recognize, and cope with low level wind shear(LLWS) hazards?

NEED ASSESSMENT FOR LESSON PLAN

The SAC Instrument Flight Center(SIFC) has requested a two hour lesson plan with a slide presentation to teach their student instructors to understand, recognize, and cope with LLWS hazards. SAC Regulation 51-37 prescribes that wind shear hazards must be part of the SIFC curriculum(29:A1-2). Additionally, SIFC requests a handbook be developed in conjunction with the lesson plan which will be utilized by the students to take notes and for future reference.

OBJECTIVES OF LESSON PLAN

1. Determine the background information required to enable SIFC students to effectively understand the causes and effects of LLWS hazards.

2. Determine what ground and airborne equipment is available to assist in forecasting and detecting LLWS hazards.

3. Determine the instructional techniques and procedures necessary to enable SIFC students to effectively teach other pilots how to cope with LLWS hazards.

VERIFICATION OF LESSON PLAN

A verifiable testing device must be developed to insure validation of the lesson plan and provide feedback to the SIFC instructors.

Chapter II

EFFECTS OF LOW LEVEL WIND SHEAR

The purpose of this chapter is to give a brief description of wind shear and explain how it affects an aircraft's normal flight path. First, a definition of wind shear and low level wind shear will be given. Then data illustrating the damage wind shear has caused to both civilian and military aviation will be used to show its costly effects. Finally, the two basic types of wind shear - horizontal and vertical - will be described. Following chapters will describe the causes of LLWS and how to recognize and cope with low level wind shear(LLWS) hazards.

The term "wind shear" refers to the "shearing" or scissor-like action of two air masses moving in relation to one another(5:78). One can see this type of motion easily in water when a rapidly moving current in a stream is contiguous with a pool of still or slowly eddying water. Their boundary is a narrow, turbulent shear zone. A trout swimming across the shear zone would have the impression of being shoved to one side, whichever direction it was headed. An airplane flying across a shear zone in air has the same feeling of being shoved. The pilot terms it hitting, or being hit by, a gust. Gusts are sudden and brief, however, while not all wind shears are of short duration. A shear zone may be several hundred feet thick and free of turbulence, and the pilot may experience it only as an unexplainable change in his indicated airspeed or in the vertical speed needed to stay on the glideslope(5:78). The shears encountered in cruising flight have their hazards, but being dumped into the ground isn't usually one of them. It's when wind shear is encountered close to the ground, during an approach or departure, that a crash may be the result. Therefore, this study will only concern itself with low level wind shear. "Low level wind shear" is shear occurring between the surface and 2,000 feet AGL, where the greatest accident potential for takeoff and landing exists(8:1).

Although wind shear can occur at any altitude, LLWS is the most hazardous because the aircraft is usually configured with gear and flaps. This high drag, low-airspeed condition makes the aircraft very vulnerable. Additionally, an aircraft's performance can be critically affected since lift depends upon the relative airflow over its wings(19:4 - 5). Wind shear can directly and dramatically change this vital dynamic pressure, and consequently, the amount of lift being produced(19:4 - 5). Other factors that have a bearing on the effects of wind shear are aircraft speed, aerodynamic characteristics, power/weight ratio, engine response, and what could be the most critical factor - the ability of the flight crew to respond(19: 4 - 5; 6:14 - 21).

Airplanes that are heavily loaded or draggy and that can't make rapid airspeed accommodations usually have the most serious problems with LLWS(5:78). These conditions tend pre-eminently to exist in large, heavy jet aircraft(5:78). Faster approach and departure speeds diminish the detrimental effects of the downward vector in LLWS. Furthermore, this provides an increased buffer above stall and gives the aircraft a greater energy tradeoff(kinetic energy for potential energy), should it be required(18:10). Light airplanes normally have no difficulty in making rapid airspeed adjustments, and therefore, have less problems with LLWS. For heavy aircraft and ones that take time to accelerate to their best climb speed, the greatest hazard of LLWS is probably not on approach, but on takeoff. (4:92)

The effect of low level wind shear is to modify normal pitch and power requirements used in aircraft ascent and descent profiles(12:11-1). Frequently an aircraft accident is inevitable when the pilot doesn't understand, recognize, and know how to cope with the hazard. The hazards that result from LLWS are of great concern in military and civilian aviation(26:14; 1:10). In the past because of LLWS insidiousness, many aircraft accidents that were categorized as pilot error or poor pilot technique may have been caused by severe wind shear. Wind shear as a cause factor was seldom listed as the primary cause of an accident or incident until the Boeing aircraft accident at New Orleans Airport on July 9, 1982(10:32). To illustrate the magnitude of the LLWS problem, from 1962 to 1982, there were 127 U.S. air carrier accidents in which thunderstorms/LLWS hazards were found to be either a cause or a factor(26:14). These accidents cost 545 lives and 260 injuries(26:14). The U.S. Air Force experienced from 1965 to 1974, 41 probable wind shear/vortex related aircraft accidents with a total price tag of 18 million dollars(1:10).

Wind shears are of two general classes: horizontal and vertical(5:78). The two types aren't separate and independent, but from the pilot's standpoint they present different problems and require different reactions. Horizontal shears are present just about everywhere, but they are not as dangerous because the velocities and rates of change are small enough to usually permit pilots and airplanes to adjust safely and in a timely manner(5:78 -79). It sometimes happens, however, that the velocities at the surface and a thousand feet above it may differ by 40 knots or more. An airplane descending through this velocity gradient has to adjust its airspeed and vertical speed noticeably to maintain a certain desired approach path(30:11-1). A groundspeed adjustment of 40 knots over a period of 20 seconds, which could easily be required, involves an acceleration as great as that during the takeoff roll(5:78). A greater adjustment may be beyond the airplane's capacity. The situation becomes hazardous only if it occurs so close to the ground that the proper adjustment to vertical speed can't be made quickly enough, or if the airplane is so heavily loaded or "draggy" that it can't make rapid airspeed adjustments. These conditions tend pre-eminently to exist in heavy jets, and they are the airplanes that have the most serious problems with wind shear. (5:78 - 79)

So far we've only talked about horizontal shears. A more serious and only recently appreciated aspect of the LLWS problem is vertical shears. These occur mostly in the company of thunderstorms; but are also common in the vicinity of fronts(5:78 - 79). The terms "downbursts" and "microbursts" refer to sinking air masses of small diameter - less than 12.5 NM in the case of a downburst, and less than 2.5 NM in that of a microburst(14:78). The smaller the worst, because the velocity gradients within the burst are steeper, and on encountering the burst, the pilot and airplane have less time to make adjustments(5:78 - 79). The effects of a vertical gust upon an airplane are distinct from those of a horizontal shear. When a vertical gust causes sudden changes in rate of climb or descent, or in position with respect to the glideslope, they are unaccompanied by changes in airspeed. The only indications are angle-of-attack and vertical velocity changes. (5:78 - 79)

Therefore, LLWS is very hazardous to large, heavy jet aircraft. It modifies their departure and arrival profiles. Because of its hazardous nature, when possible, aviators should avoid LLWS. Next, the most common causes of LLWS will be covered, which along with the detection chapter should help in its avoidance.

Chapter III

CAUSES OF LOW LEVEL WIND SHEAR HAZARDS

This chapter will provide background information on the causes of LLWS hazards. Cause cognizance will help in understanding hazard recognition and control which will be covered in subsequent chapters. The meteorological phenomena producing low level wind shear are, primarily:

1. thunderstorms;
2. fast-moving warm and cold fronts;
3. land/sea breezes frontal action;
4. on occasion, mountain waves or funneling winds;
5. and, less frequently, low level jets over radiation inversions(26:197; 30:11-3).

1. THUNDERSTORMS

Wind shear hazards associated with thunderstorms are the most hazardous due to the severity, complexity, and multiplicity of the shears produced(8:2). Wind shear can occur on all sides of the thunderstorm and in the downdraft directly beneath the cell. Since gust fronts associated with thunderstorms can precede the actual storm by 15 miles or more, low level wind shear should be expected whenever thunderstorms are present. (8:2) Even more complex and unpredictable wind shear patterns can result when there are numerous mature cells in the vicinity(17:5).

The wind shear hazards associated with thunderstorms can be grouped into four categories based on size, duration, and effects. Any thunderstorm may have one or more of these categories present, and the grouping is only for explanatory purposes. The four categories are: (1) high- based cumulus clouds; (2) "first gusts"; (3) large downbursts or "macrobursts"; and (4) "microbursts." The following discussion of these categories will proceed from the least to the most hazardous.

The first type LLWS hazard associated with thunderstorms is "high-based, cumulus-type clouds." High-based innocuous-appearing, cumulus clouds can be the root of severe downdraft and strong wind shear(7:10). This type thunderstorm is a common problem in the western United States and can have cloud bases above 8,000 feet AGL(18:27). An airliner accident at Denver in August 1975, was due to this type thunderstorm. Surface winds were light, but after takeoff, the aircraft flew into an outflow segment with tailwinds between 60-90 knots. Predictably, a 60-90 knot loss of indicated airspeed at 200 feet AGL caused the aircraft to stall and fall. (18:26 - 27)

This dangerous phenomenon occurs when rain falling from high -based clouds chills the air causing a down flow. The extremely dry air into which the rain falls provides further refrigeration because of the evaporation of the water droplets. (This evaporation process is the heart of most refrigeration systems.) (7:10) The combination of rain chilling and evaporation cools the downdrafts well below the temperature of the surrounding air. It falls in a great cascade flowing down below the cloud until it is either dissipated by winds, or by other mixing, or until it reaches the ground to blow outward from the center of the downdraft. If the latter occurs, it will cause brief gusty surface winds. Light sprinkles or showers of rain may be reported if the evaporation process has not been completed before the rain reaches the ground. The rain and strong wind gusts virtually assure the presence of strong downdrafts and outflows. The effects of the downdraft and outflow as the aircraft passes through will be brief but they could be devastating. (7:10) Case histories indicate that this hazard may be expected under high-based cumulus clouds whenever the following conditions are present:

a. high-based cumulus type clouds with virga;
b. very dry surface air with a dew point spread of 35 degrees F or more;
c. weak winds from the ground to the cloud bases - generally less than 15 knots(any stronger winds would cause mixing and the down current would be destroyed); and the
d. temperature is warmer than 75 degrees F(7:10 - 11).

Reports of gustiness in otherwise light surface winds and brief light showers confirm the existence of strong downdrafts and the accompanying outflow from these storms. It is prudent not to be lulled into a false sense of security because of the apparently innocuous appearance of high-based cumulus clouds. (7:11)

The next category of wind shear hazards associated with thunderstorms is the "first gust." The first gust is a rapid shift and increase in wind just before a thunderstorm hits(15:6). The gusty winds are associated with mature thunderstorms and are the result of large downdrafts striking the ground and spreading out horizontally. These winds can change direction by as much as 180 degrees and reach velocities of 100 knots as far as 15 miles ahead of the storm(15:7). The gust wind speed may increase as much as 50 percent between the surface and 1,500 feet, with most of the increase occurring in the first 150 feet(15:6 - 7). The implications for a shear on approach or takeoff in such a case are obvious.

The third and fourth categories of wind shear hazards associated with thunderstorms - "macrobursts" and "microbursts" - are both in the form of "downbursts" from mature thunderstorms(13:78). The only real difference between large downbursts(macrobursts), and small ones (microbursts), is their size and duration(13:78). Of all the thunderstorm's hazards, the "downburst" is the most subtle; yet it can be as deadly as a tornado. The downdraft helps produce the gust front that spreads out ahead of a mature thunderstorm and the destructive turbulence inside(28:11-4).

Although a downburst at the upper extreme of intensity can cause tornado-like damage on the ground, the greater danger to aircraft probably comes from downbursts at low altitude during takeoff and landing. Since the downburst covers a relatively small area and doesn't last long, there may be no warning of its existence until it is too late(3:12 - 13). The downburst is an extremely intense localized downdraft from a thunderstorm and can exceed 720 feet per minute vertical velocity at 300 feet AGL(13:78).

The "macroburst" ranges from 2.6 to 12.5 NM in width and lasts five to 20 minutes(13:78). Large-scale downdrafts, funneling out of thunderstorms to produce gust fronts, are 12 NM or more across and last much longer(13:78). The power of the downburst can actually exceed aircraft climb capabilities, not only those of light aircraft, but even a high performance Air Force jet. The downburst is usually much closer to the thunderstorm than the "first gust," but there is no absolutely reliable way to predict the occurrence. One clue is the presence of dust clouds, or roll clouds, or intense rainfall(15:6 - 7). It would be best to avoid such areas.

The final category of wind shear hazard associated with thunderstorms is the "microburst." Microbursts were only identified recently - mid 1970s - and present special problems because of their insidiousness(3:78). A microburst is an intense, highly localized downburst with velocities of 60 knots or more that hits the earth and spreads out horizontally in a radical burst of violent wind(3:78). It may originate beneath any type of convective cloud and is just as likely to develop in a little or no rain situation as in a very heavy rain storm. By definition, "microbursts" are .25 to 2.5 NM in diameter and two to 10 minutes in duration(3:78). The greatest probability of development occurs during the spring and summer months in the mid to late afternoon(16:8). (See figure 1 below)

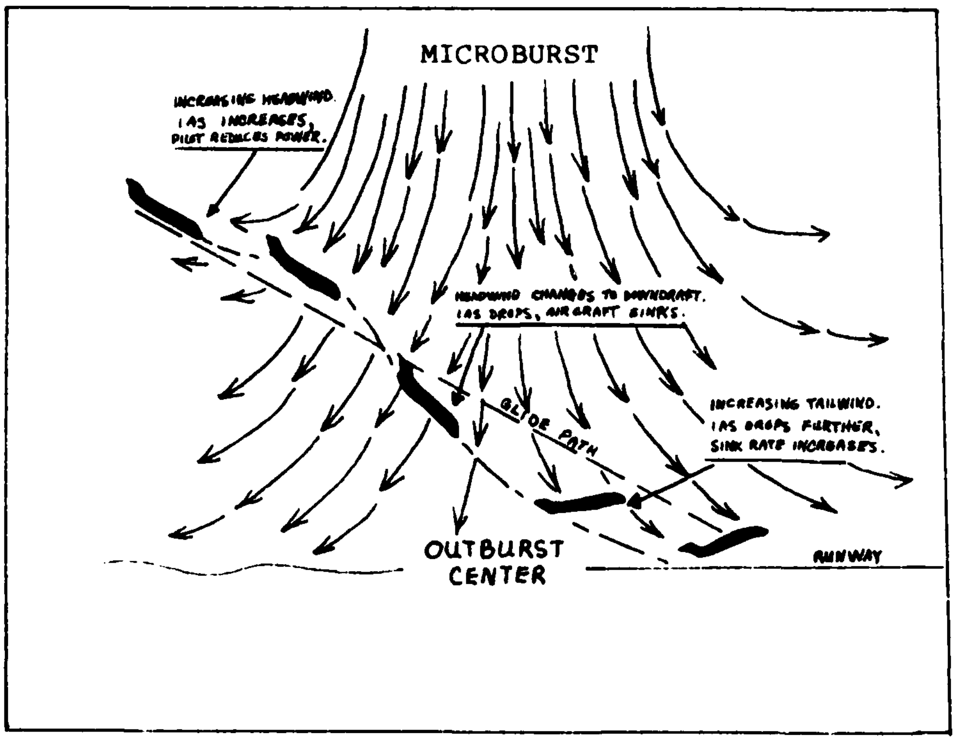


FIGURE 1

Microbursts strike the ground and spread radially, spawning violent, low level wind shears. These wind shears can strike aircraft quickly, dangerously, and without sufficient warning. Its the intensity, compactness, and short-lived nature of microbursts that make them so insidiously dangerous. An aircraft encountering a microburst first experiences a headwind, increasing lift. Yet only moments later it's caught in a tailwind, decreasing lift; sometimes to the point of a stall. (See Figure 1 for microburst depiction) Small aircraft normally can respond quickly to such abrupt changes. Unfortunately, a heavily loaded airliner taking off, such as the Boeing 727 which crashed at New Orleans in July of 1982(2:34), or a jet making a final approach at 60 percent power, has more difficulty - six to eight seconds are needed for the engines to reach full power(13:78). If the microburst strikes at 500 feet AGL or below, there is often not enough time to respond(13:78).

A microburst can create other kinds of havoc, too. Loss of lift is probably one of the most critical. Also, there's the force of rain water on the plane. Even rain beating on the wings changes the aerodynamics, adding to the decreasing lift. "As aircraft have grown larger and air traffic volume heavier, microbursts have become more of a danger," says the man who first identified microbursts, Dr. Tetsuya Fujita of the University of Chicago(13:78).

Microbursts of mean intensity produce horizontal differential velocities of approximately 55 knots, while the strongest can produce differentials in excess of 100 knots(16:8). In fact, many microbursts are so severe that being hit by one at the right point in space and time, like during a takeoff or approach, will almost certainly result in disaster, regardless of aircraft type. In case you're thinking this phenomenon is a rare occurrence, guess again. The extent of microbursts in nature is far greater than anyone ever expected(16:8).

A microburst has three distinct phases as an aircraft traverses it. The main force is downward with an associated gust front that moves outward radially from the focal point of the microburst as it nears the earth(16:8). Initial signs of a pure headwind burst should include an increase in indicated airspeed(IAS) and a nearly constant angle of attack(AOA). This increase in dynamic pressure, with a relative constant coefficient of lift, generates additional lift. As a result, aircraft performance increases and a higher-than-normal flight path is achieved(16:9).

The headwind phase begins to develop a downward vector component as the wind pattern transitions to the downburst phase. During this period, the resultant relative wind continuously reduces the AOA. As the downburst phase is entered, cockpit indications will register a further reduction in AOA, accompanied by decaying IAS. As the flight profile continues, both IAS and AOA will be continually reduced, with more critical deterioration in aircraft performance(16:9). Obviously, some extreme measures may be required to survive. In many situations, it takes only a relatively small reduction in AOA(less than 10 degrees) to critically affect the aerodynamic performance of the airfoil. Furthermore, a severe reduction toward negative values can result in near zero generation of lift, with or without significant losses of indicated airspeed. Rotating the aircraft to a higher deck angle can change the AOA to a more favorable reference(16:10). The application of maximum thrust will normally serve to accelerate the aircraft mass, thereby generating a new relative wind and AOA, and placing the aircraft in a safer flight regime. Prior to the encounter, faster approach and departure speeds diminish the detrimental effects of the downward vector components. Furthermore, this provides an increased buffer above stall and gives the aircraft a greater energy tradeoff, kinetic energy for potential energy, should it be required(16:8 - 10).

The discoverer of "microbursts," Dr. Tetsuya Fujita of the University of Chicago, is an authority on violent storms(13:80). Fujita gained prominence for his investigation of the 1975 crash at Kennedy Airport, where a Boeing 727 settled into the ground during an ILS approach in a thunderstorm(5:77). At the time it was generally assumed that a gust front had brought the plane down. Fujita was suspicious of that explanation. Gust fronts form the leading outflow of thunderstorms and, therefore, are wide spread. Yet, some of the planes landing just prior to Flight 66 reported no difficulties, while others reported severe wind shear with head and tail winds. Fujita knew that the Boeing 727 was less than 500 feet AGL when it lost control. "I felt that this meant the downdraft was coming down from above and moving outwardly close to the ground, like water from a garden hose spraying straight down on a concrete sidewalk," he said(13:80).

Initially, most meteorologists did not accept his theory, but in 1978 he confirmed his suspicions by recording downbursts and microbursts on doppler radar at Chicago's O'Hare International Airport in a study called "The Northern Illinois Meteorological Research on Downbursts"(13:80).

Thus, microbursts were born. These investigations and other studies lead to the Joint Airport Weather Studies(JAWS) project which is covered in the next chapter in detail(13:80).

Microbursts are a frequent occurrence, but if a plane does not encounter one below 500 feet AGL, it usually isn't a problem. However, what may be a fairly common meteorological event is a rare event in terms of encounter. The probability of getting grabbed by a microburst is low, but the consequences if you do are high(24:151).

2. FRONTS

In addition to thunderstorms, certain frontal systems are the most prominent cause of significant LLWS problems at or near airports. Winds can be significantly different in the two air masses which meet to form a front(23:6). Both warm and cold fronts cause wind shears(18:27). However, not all fronts have associated wind shear(15:5). Furthermore, turbulence may or may not exist even if the front contains wind shear. But if the surface wind under the front is strong and gusty, there will be some turbulence associated with it(23:7).

In fact, shear is normally a problem only in those fronts with steep wind gradients(15:5). Like so many things in weather, there is no absolute rule, but there are a couple of clues. Fronts that are most conducive to significant wind shear are fast moving(30 knots or more) and have at least a 10 degree F(5 degree C) temperature differential(15:5 - 6). You can get these two clues in the preflight weather briefing, and if they are present, be prepared for the possibility of shear on takeoff or approach.

While the direction of winds above and below a front can be accurately determined, existing procedures do not provide precise, current measurements of the height of the front above the airport. The following general guidelines can, however, determine the probability of LLWS in a particular type front. First, wind shear associated with a warm front is more dangerous to aerodrome operations. Data compiled on wind shear conditions indicate the amount of shear in warm fronts is much greater than in cold fronts(23:6 - 7). Strong winds aloft, associated with the warm front, may cause a rapid change in wind direction and speed where the warm air overrides the cold, dense air near the surface. Warm frontal wind shear may persist six hours or more over an airfield ahead of the front because of the front's shallow slope and slow movement. Further, low ceilings and visibilities frequently associated with warm fronts may compound aircrew problems(30:11-5). Once the warm front passes the field the problem ceases to exist(23:7).

Second, LLWS hazards associated with a cold front are usually less dangerous because normally the danger area is of shorter duration and no low visibilities are present. LLWS occurs with a cold front after the front passes the airfield. Because cold fronts have a greater slope and normally move faster than warm fronts, the duration of LLWS at a station is usually less than two hours(15:5 - 6).

Therefore, the key points to remember about fronts and LLWS are listed below.

a. Warm Fronts have:

(1). relatively shallow slopes(about 1/2 degree);
(2). their shear reaches the airfield six to 12 hours before warm frontal passage at the surface;
(3). with associated restricted visibility being ahead of the frontal passage, and thus, also a problem.

b. Cold Fronts have:

(1). relatively steep slopes(but less than 3 degrees);
(2). produce LLWS 30 minutes to one hour after frontal passage at the field;
(3). and associated restricted visibility is behind the front, and thus, is not a problem.

3. LAND/SEA BREEZES

Large bodies of water can create local winds due to the differences in temperature between the land and water. Airfields located adjacent to large lakes, bays, and oceans can experience LLWS due to these localized winds(8:3). The flow to or from the water is caused by differential heating and cooling of land and sea surfaces. The sea breeze is a small scale frontal boundary and can reach speeds of 15 to 20 knots. It can move inland 10 to 20 miles, reaching its maximum penetration in mid to late afternoon(8:3). Land breezes occur at night because the land becomes cooler than the water. The land breeze has less intensity than the sea breeze, and unless aircraft penetrate it on a long, low approach over water, there is little threat to flying safety(30:11-6).

4. MOUNTAIN WAVES OR FUNNELING WINDS

Certain airfields located near mountain ranges are infamous for the treacherous winds that frequently exist. These winds are caused by funneling. The terrain is such that the prevailing winds force a large mass of air to be channeled through a narrow space, such as a canyon or pass, where it is accelerated and then spills into the flight path of aircraft(30:11-5). These winds sometimes reach velocities of 80 knots(30:11-6). Strong surface winds blowing through these canyons or passes can cause serious localized wind shears during departures and approaches. The real problem with such shear is that it is almost totally unpredictable in terms of magnitude or severity. A pilot can expect such shears whenever strong surface winds are present(15:7).

Contributing to the severity of surface winds at airports near mountain ranges is the phenomenon known as mountain waves. Mountain waves often create LLWS at airports that lie downwind of the wave. A strong mountain wave can extend 300 miles downwind of a mountain range(8:3). The presence of rotor clouds(roll clouds) and/or lenticular(lens shaped) clouds are good indicators of wind shear. The absence of these clouds, however, does not necessarily indicate no shear or turbulence, just the fact that there may not be enough moisture available to form a cloud(8:3). Therefore, caution is required when conducting air operations near mountains or along straits and channels as LLWS is a strong possibility.

Even small hills or large buildings that lie upwind of the approach or departure path when combined with strong winds can produce localized areas of shear. Observing the local terrain and requesting pilot reports of conditions near the runway are the best means of anticipating wind shear from this source. This type LLWS can be particularly hazardous to light airplanes(23:6). Gusty winds are associated not only with the previously mentioned pnenomenon, but also with several others, including the Chinook and Foehn winds in the western United States and Europe, respectively, and sea breezes(8:3).

5. LOW LEVEL JETS OVER RADIATION INVERSIONS

Pilots who have flown in the southwest or in southern California or Colorado are familiar with this weather pattern. Overnight cooling creates a temperature inversion a few hundred feet above the ground. This, coupled with high winds from what is known as the low level jet, can produce significant wind shears close to the ground(15:7). The low level jet often forms just above a radiation inversion. It starts to form at sundown, reaches maximum intensity just before sunrise, and is destroyed by daytime heating(usually by 10 A.M. local time). The low level jet is observed in all parts of the world at all times of the year(30:11-5). However, it is most common in spring and summer. In the conus, it commonly occurs in the great plains. The eastern seaboard from North Carolina to Maine is another favorite location(18:27). The cooling of the earth creates a calm, stable dome of cold air 300 to 1,000 feet thick, termed an inversion layer. The low level jet occurs just above the top of the inversion layer, and while speeds of 30 knots are common, wind speeds in excess of 65 knots have been reported. (30:11-5) Anytime a radiational inversion is present, the possibility of low level wind shear exists.

Chapter IV

RECOGNITION AND DETECTION OF LLWS

This chapter will discuss the equipment and procedures available for forecasting and detecting LLWS. First, the difficulty of forecasting and detecting LLWS will be addressed. Then, research and development by the FAA and civilian industry on LLWS forecasting and detection equipment will be covered. Finally, the equipment and procedures available to USAF crew members to detect LLWS will be discussed.

The problems of detecting wind shear, let alone predicting it, are considerable. It cannot be seen, and a huge volume of air must be searched if all major airports are to be protected. Nevertheless, technological progress has been made in improvements of forecasting equipment and ground-based and airborne detection systems(5:77 - 79). At the same time, disagreement and uncertainty persist as to the exact nature and frequency of hazardous wind shears, and what pilots can do about them.

The current concern over wind shear grew originally out of a 1975 accident at Kennedy Airport, where a Boeing 727 crashed during an ILS approach in a thunderstorm(5:77). Simulations of the flight path of the jet led to the conclusion that it had encountered vertical gusts so powerful that it could not climb through them to remain on the glideslope. The idea of intense, localized vertical gusts close to the ground was something new. The discoverer of this phenomena, Theodore Fujita of the University of Chicago, coined the glamorous terms "downbursts" and "microbursts" to describe these intense vertical gusts. (5:77 - 79)

As a result of the Kennedy accident makeshift wind shear detection systems were installed at many major airports(10:32). These primitive detection systems consisted of nothing more than a few anemometers scattered about the airport, and a buzzer in the tower that goes off when local differences in wind velocity exceed certain limits. Towers began issuing warnings of possible wind shear to pilots who, while duly alarmed, weren't too clear about what they were supposed to do about them. Once the theoretical basis for the Kennedy accident was accepted scientifically, it was possible to explain a number of other airline accidents. Thus, the development of wind shear prediction techniques and detection equipment became a priority of the Federal Aviation Authority(FAA)(5:77 - 79).

Since 1975, the FAA has been investigating three areas for possible solutions to wind shear detection problems. These three areas are: improved forecasting and prediction; ground-based sensors; and airborne detection devices(26:30). The recommendations for solution to these three areas will be covered later in this chapter. However, they must be pointed out now because they provide a frame of reference for research done on this subject.

One of the most important of these studies was a project called the "Joint Airport Weather Studies(JAWS)"(13:78). It was conceived in 1980 as an outgrowth of three other scientific investigations(13:78). JAWS was a $2.2 million, three-year project conducted by the National Center for Atmospheric Research and the University of Chicago(13:78) Its principal objective was to acquire additional basic knowledge on microbursts and their environment to aid in their detection and prediction(26:158).

The JAWS project developed what is now the promising detection system for wind shear; the late real-time doppler radar and doppler lidar(13:78). The common name for this radar is next-generation weather radar system(NEXRAD)(26:30). Unlike conventional weather radar that simply measures the overall speed and intensity of a storm, doppler radar can see what's happening inside a storm. This allows the measuring of internal wind velocities and directions. Operating on the same principle as police speed-detection radar, doppler radar measures the frequency shift of its signal bounced off rain drops being blown about in the storm's winds. The doppler lidar sends out a laser beam to measure the aerosols such as dust and salt; it can even sense insects borne by a breeze. Its effectiveness is limited in rain, but is extremely useful when the air is clear. (13:78-80) A large collection of data-gathering devices were assembled to address LLWS: three pulsed, microwave doppler radars; two pulsed, CO_2 doppler lasers; 41 surface automated weather stations; and five research aircraft(26:159). The research aircraft included one airborne doppler lidar system for wind shear detection, and one airborne research microwave doppler radar system(26:159). Balloon soundings, as well as soundings from 48 automated surface stations(27 of them sonar powered) rounded out the data(13:78).

All research activities were concentrated around Denver's Stapleton International Airport. LLWS "warning systems" that were tested included the low level wind shear alerting system(LLWSAS) of the FAA. A similar National Center for Atmospheric Research(NCAR) ground-based wind system of a greater density than the LLWSAS, a pressure jump sensor array, and three airborne systems were also tested. The airborne systems included: the airspeed and ground-speed procedure concept; an airborne laser, detection system; and the Smith's Industries vertical velocity/energy rate system. Finally, one of the NCAR pulsed microwave doppler radars was placed at the airport center as a primary detection and warning system. (26:159).

The results of the JAWS test showed that microbursts were quite common in Denver and although small and short-lived, can be lethal(26:160). In 91 days of field operations, JAWS recorded 62 microbursts(13:78-80). Accidents involving microbursts are rare because the space-time window is very small when a jet aircraft will encounter a microburst below 500 feet AGL. The current FAA LLWSAS system appears to be inadequate to detect and warn of microburst occurrence primarily because microbursts are smaller than the LLWSAS detection scale. It appears that current training simulators do an inadequate job of responding to wind shear gust imputs since the microburst signal is likely to excite this mode in a manner critical to jet transport safety. Furthermore, it showed that current wind shear models used in simulation are inadequate because they do not provide the microburst scale with sufficient resolution to be accurate and useful. The test showed that an airport-located pulsed microwave doppler radar can provide increase in aviation system protection from dangerous wind shear. Therefore, while JAWS has yet to answer all the meteorological questions, it has answered about the technology necessary for accurately detecting wind shear. (13:78-80)

Wind shear research results were reported to Congress in a technical report by Mr. Peter M. Kuhn, senior research scientist for Northrop Services, in August of 1982. In a hearing before the Committee on Science and Technology of the U.S. House of Representatives, he addressed the need for improvement of wind shear detection methods(26:195). The report underscored the need for in-cockpit alerts of wind shear for takeoffs and landings(26:196).

Mr. Kuhn's report indicated that a CO_2 molecular spectrum can sense atmospheric temperature at various distances ahead of an aircraft. A 13 to 15 micrometer of the spectrum can be used by an aircraft to remotely sense LLWS in and around thunderstorms and gust front conditions. This is possible since there is a difference in temperature between peak gust areas and ambient non-sheared areas of the front or thunderstorm environment. A radiometer in the system senses this difference well ahead of penetration. This infrared(IR) band radiometer with several designed forward-looking distances of from 2NM to 6 NM senses an average air temperature along a forward horizontal path. Any sudden or rapid cooling of the surrounding air indicates the presence of LLWS. (26:196 - 198) Then the difference between this forward air temperature and the static air temperature at the aircraft is measured, and alerts the crew of possible wind shear forward of the aircraft(26:196).

Therefore, an IR forward-looking, thermal radiometer detector can be used to detect LLWS. To understand how this principle works requires a scientific explanation of what happens in a downburst. The technological analysis of a downburst can be explained as follows:

> Negative buoyancy, the driving force in the downdraft producing a downburst, originates from the cooling of the subsiding air principally through evaporation of percipitation. As the downdraft approaches the surface it decelerates to zero as energy trades between the vertical and horizontal components of the downdraft. As the downdraft spreads out along the surface, horizontal components of velocity approach a maximum. Thus, it is shown that the temperature deficit of the downdraft is a good indicator of its strength and the horizontal wind resulting in shear behind the gust front.
>
> Behind the gust front the cool horizontal outflow current can develop a strong vertical shear near the surface. The severity of this vertical shear increases with the magnitude of the temperature drop or deficit, it therefore is possible to infer the probable strength of the vertical wind shear behind the gust front, and above a certain threshold, indicate a warning. An indicator found to be acceptable in the identification of a warning is the change in temperature sensed, forward IR radiometer sensed air temperature minus the static air temperature at the aircraft observed over a unit time. (26:198)

The meteorological basis for wind shear alerts is the relation... that the colder the downdraft the higher is likely to be the scale of the outflow wind. Since the relation of the wind to the wind shear generated is geometrical, the scale of the wind shear also increases with the size of the negative temperature perturbation of the downdraft. The lower threshold for severe wind shear corresponds to a negative temperature perturbation of about 4 degrees C. Fujita estimates that a negative temperature perturbation of about 4 to 9 degrees C can result in hazardous gust front damage. At the upper end of this scale wind damage to property and vegetation begins to mount.... (26:199)

The IR warning system displays the gust front temperature drop 70 seconds or 3 miles ahead of the shear area.... (26:205) As the aircraft approaches sufficiently cold outflow the radiometer system will progressively record a temperature depression of increasing magnitude. This will manifest itself in a changing or upgraded and updated warning of the impending shear area. This provides the airborne IR system with a degree of peripheral vision by horizontal scanning to the left and right of the forward direction or by a shaped mosaic of detectors utilizing a common optical system thus providing the pilot with avoidance(directional) alternatives(26:210)

The recommendations by Mr. Kuhn in his report consisted of three primary approaches for "forecasting" of wind shear hazardous to safe aircraft operations(26:211). While these three approaches were all short-term, each was low-cost. All of these forecasting approaches can be accomplished in the long range by the development of NEXRAD. NEXRAD is the next-generation weather radar system. It is a doppler radar system that will improve the recognition of wind shear, gust-fronts, downbursts, and other potentially hazardous weather conditions(26:30).

The first approach was using IR, forward-looking, thermal radiometer detectors for airborne LLWS detection. The previous airborne testing had shown the success of this critical cockpit sensing and pre-warning system. Symbolic or color display could be used to indicate areas of probable, hazardous wind shear(26:212). Then the spectral IR data taken at a fixed azimuth would be inverted and converted into a temperature grid distribution (26:212). Therefore, a low cost radiometer would provide a grid distribution of hazardous shear conditions, and provide the pilot with additional wind shear information(26:212).

The second approach involves using a ground based IR scanning and ranging thermal radiometer for ground LLWS detection. A 360 degree circular scan could be made by the ground based IR scanner at low elevation angles. This would give the identical grid and ranging of the airborne IR system. This system would be helpful to pilots when making takeoff decisions near LLWS producing phenomena. (26:212)

The third approach is a surface network of anemometers. This system would be more expensive as it requires a large number of ground units and elaborate uplink communications. Furthermore, present instrument calibration scales small enough for microburst measurements have not been developed. Therefore, this third approach was discouraged, even though it has already been implemented at some major airports. (26:212 - 213)

The results of this Congressional hearing in August of 1982 led to another study mandated by Congress in March of 1983(10:32). The FAA in March of 1983 awarded a $275,000. contract to the National Academy of Sciences to conduct a three month study of LLWS and its effect on aircraft. The contract calls for the establishment of a joint committee composed of two panels that will study LLWS variables and aircraft performance and operations. The LLWS panel will review current techniques used to determine and track wind shears and will recommend a series of changes to improve the FAA's ability in predicting the weather phenomenon. The aircraft performance panel will review the vulnerability of aircraft operating in wind shear conditions and recommend changes when necessary in operational procedures. (10:32)

The National Academy of Sciences through the National Research Council Study of 1983 recommended both near and longer term actions to alleviate the effects of wind shear(9:62). The study concluded that most pilots are not adequately trained to cope with wind shear situations and that "an education campaign directed at all classes of pilots" offers the nearest term prospect of reducing the risk. Another near term means of easing the threat is to improve and expand the LLWSAS already installed at 59 major airports. Other recommendations made by the Study included: (1) development of improved airborne systems to enhance flight crew ability to recover from wind shear encounters; (2) deployment of special doppler radars at large airports to increase prospects of detecting wind shear conditions in the terminal areas; (3) research on aircraft behavior in wind shear conditions, including the effect of heavy rain, which often accompanies those conditions; (4) devise optimum control procedures for flight crews; and (5) additional research for fuller understanding of wind shear to enable meteorologists to provide more accurate and timely forecasts. (9:62-63)

The LLWSAS referred to in the 1983 study is installed at 58 airports, with 51 more scheduled for installation in 1984-85. It consists of an array of wind speed and direction sensors mounted on towers in the terminal area. A typical array consists of one sensor at a mid-airport location and five outlying ones located about two miles from the center site. All sensors feed a microcomputer that is programmed to detect a 15 knot vector difference in wind speed between a two mile average of winds at the center sensor and any of the outlying sensors. When this occurs, aural and visual alarms alert controllers in the airport control tower. The cost of such a system is around $200,000. (9:62)

The study reported that an airborne continuous-wave laser doppler radar(lidar), developed by the British, was tested on a British Aerospace HS-125 during the JAWS program to assess its ability to detect wind shear conditions. The study noted that even though effective sensors were demonstrated in JAWS, it is still necessary to have high speed data processing and communications to assure that alarm conditions quickly reach traffic controllers and flight crews. The conclusion of the study was that until more effective sensors are developed on the ground or in aircraft, PIREPS may be the single most important safety item in identifying most hazards to aircraft operations. (9:62-63)

In discussing airborne instruments designed to help a flight crew safely cope with wind shear conditions, the study cited systems being offered by Safe Flight, Britian's Smiths Industries, and France's Sfena. The latter two display additional information on existing instruments while Safe Flight employs a separate cockpit display. The study did not attempt to evaluate the effectiveness of these airborne systems, noting that "the extent of their individual usefulness for particular aircraft has yet to be established." The study did note that AOA sensors long have been available commercially. These, it concluded, are considered to be an obvious and highly desirable aid in achieving maximum climb performance, so necessary to the successful transit of severe wind shear. (9:62-63)

A general summary of the results from all this research has developed three possible solutions to wind shear detection problems: first, improved forecasting and prediction; second, ground-based sensors; and third, airborne detection devices.

First, forecasting and prediction improvements were made by the work of the National Weather Service and the National Severe Storms Laboratory which developed and implemented improvements in the forecasting of frontal wind shears. These forecasts are currently made by the National Weather Service local forecast offices. These offices are now able to predict shear conditions associated with fronts. Forecasts of this type are included in weather warnings to airmen. While we are still not able to predict accurately shear conditions associated with thunderstorms, this type of forecasting will be greatly improved by the development and implementation of the next-generation weather radar system(NEXRAD)(26:42). The NEXRAD is a doppler radar system that will improve the recognition of wind shear, gust-fronts, downbursts, and other potentially hazardous weather conditions. (26:41 - 42)

NEXRAD implementation will be in four phases. The first phase, completed November 1982, is called system definition. Its purpose was to determine the capabilities of the operational system and how best to balance the different priorities of air traffic controllers, airport operators, and aviators at minimum cost. The second phase, validation phase, began in June 1983, and in it contractors will design, build, and test two competing pre-production models of the operational NEXRAD system. The third phase, production, is scheduled to begin in 1986. The final phase, installation, will begin field installation of operational systems in 1987. (26:41 - 42)

The second possible solution to the wind shear detection problem is ground-based sensors. Many airports have ground detectors known as Low Level Wind Shear Alert Systems(LLWSAS). The LLWSAS consists of an array of wind sensors distributed about the airport and connected to a central processor that sounds an alarm to the tower whenever the wind vectors at two sensors differ by 15 knots or more. Fifteen knots is not enough of a shear to bother most airplanes, and so the LLWSAS is more of an alert system than a warning system. Furthermore, its limitations are obvious; it measures only surface winds, cannot access vertical components, and cannot give pilots useful information about events of small extent and short duration, like microbursts(4:94 - 95). They are also inadequate to detect and warn of microburst occurrence primarily because microbursts are smaller than the LLWSAS detection scale(13:78) To date, a total of 58 systems have been installed. Pending the outcome of Congressional actions on

FAA authorizations and appropriations, current planning is for 51 additional systems to be operational by the end of 1985(26:44).

The third possible solution to wind shear detection problems is airborne detection devices. Airborne flight simulations of airborne devices for the detection and display of wind shear information in the cockpit have been successfully demonstrated(26:42). The JAWS project utilized IR forward-looking thermal radiometer detectors which successfully detected wind shear up to six NM forward of the test aircraft(26:196). Although, JAWS demonstrated the technology to make this feasible, it has not yet become operational.

Today, the USAF does not have the equipment for continuous, accurate measurement of LLWS. The anemometers used at Air Force bases measure only surface winds. The most dangerous shear occurs above the surface. Other devices such as rawinsonde and pilot balloons are used to obtain weather data, but the location and frequency of measurement limit their effective use in detecting wind shear. Current USAF weather radar can detect precipitation associated with thunderstorm activity, but cannot detect the movement of air associated with a downburst. We have used PIREPs for many years, but they are not consistently available when and where they are needed. Timely transfer of available information to the aircrew also presents a problem. The Air Force has proposed the development of a Low Altitude Wind Warning System(LAWWS). The approval, funding and development of the proposed LAWWS have not yet been completed, but positive action is being taken to provide an operational system in the future. (1:10 - 11).

Even though USAF does not have the equipment necessary to accurately measure LLWS, there are ways crew members can alert themselves to the possibility of a wind shear condition and detect it when encountered. Until the USAF develops better equipment for LLWS detection, we must continue to rely on current procedures and techniques for its avoidance(1:11). Air Force and MAJCOM directives give us broad guidance for weather avoidance(27:5-5). Air Force pilots are directed not to takeoff, depart, or land when thunderstorm activity is producing local effects at the airfield(27:5-5). Flight manual technical orders give general aircraft procedures for dealing with low level wind shear. AFM 51-12, Vol 1, pages 11-6 and 11-7 list many indications of LLWS. All of these directives warn us of the dangers of LLWS, but give little guidance on how to detect it.

However, there are numerous information sources readily available which can be helpful in detecting LLWS. These sources include: (1) preflight weather forecasts; (2) PIREPS; (3) PMSV; (4) air traffic control(FAA and tower personnel); and (5) aircraft instruments(2:3). Each of these sources provide useful information for the exercise of sound pilot judgment in detecting and coping with LLWS.

The best way to anticipate LLWS for departure or at your destination is from the preflight weather briefing(8:3). Don't hesitate to ask the forecaster about the possibilities of LLWS. If thunderstorms are observed or forecast at or near the airport, be alert for the possibility of LLWS in the departure or arrival areas. Check the surface weather charts for frontal activity. Determine the surface temperature difference immediately across the front and the speed the front is moving. A 10 degree(F) or greater temperature differential, or a frontal speed of 30 knots or more, are indications of the possible existence of significant LLWS(30:11-6;11-7). However, the intensity of LLWS is not readily determinable, because no standards have yet been derived. Therefore, a LLWS forecast consists only of a yes/no type forecast. As a result, even if you know that wind shear will be present, there is no standard way to compensate for it(8:3).

Watch for pilot reports(PIREPS) of wind shear. PIREPS are a major source of weather information; they provide real-time data to the weather forecaster(8:3). The Airman's Information Manual recommends that pilots report any wind shear encounter to Air Traffic Control. This report should be in specific terms and include the loss or gain of IAS and the altitude at which it happened. This simple report is extremely important so that the pilot of the next airplane in sequence can be forewarned. Reported LLWS that causes airspeed changes in excess of 15 to 20 knots should be avoided(30:11-7).

PMSV, FAA, and tower personnel are excellent sources to keep you updated on both the latest weather information and the latest PIREPS. Do not hesitate to make contact with these agencies well in advance of your destination to update your weather information. Be sure to ask about the presence of LLWS. Remember that LLWS can exist even when the sky is clear(8:1 - 2). Assume that severe LLWS is present when the following conditions exist in combination: (1) high based cumulus type clouds with virga present; (2) the surface air is dry with a dew point spread of 35 degrees F or more; (3) the surface winds are weak - generally less than 15 knots;

and (4) the surface temperature is warmer than 75 degrees F(7:10 - 11).

Finally, aircraft instruments provide information of possible wind shear problems(8:1 - 2). The best indication to the aircrews that the aircraft is encountering wind shear occurs on the instrument panel. Fluctuations in the indicated airspeed(IAS) and the vertical velocity(VVI) always accompany wind shear. Another indication is a large difference between IAS and ground speed. Any rapid change in the relationship between the two represents a wind shear. Crews in aircraft equipped with an inertial navigational system(INS) can compare the wind at the initial approach altitude with the reported runway surface wind to see if there is a wind shear situation between the aircraft and the runway. Remember, INS winds are in degrees true, surface winds are reported in degrees magnetic. This will make little difference at airfields where variation is only a few degrees, but it makes a considerable difference when variation is 20 degrees or greater. (30:11-7).

For airplanes which don't have INS or ground speed readouts, monitoring aircraft performance can reveal wind shear conditions. By observing the aircraft's approach parameters - rate of descent, power setting, and pitch attitude - pilots can obtain a feel for the wind they are encountering. If the runway surface wind is reported as calm but your indications at the final approach fix(via INS, doppler, or VVI) tell you that a 20 knot headwind exists at your altitude, then you can expect to lose 20 knots of IAS somewhere on final. Comparing wind direction and velocity at the initial phases of the approach with the reported surface winds provides an excellent clue to the presence of shear before it is actually encountered(30:11-7).

Remember, wind shear is a result of a change in direction and/or velocity of wind. An aircraft is affected by this change because the aircraft motion relative to the ground is also changed by the wind. Changes in energy cause changes in aircraft position and speed. In unaccelerated flight an aircraft maintains a certain energy level, balanced against the surrounding atmosphere. If this balance is disturbed, by a wind shear, for example, some compensation must be made. Events in an aircraft are dynamic, and the aircrew is continually reacting to the changing flight conditions. Changes in wind velocity or direction are part of these dynamic conditions. The crew perceives the need for a change in aircraft energy levels through the instruments and makes changes. The applied corrections are not, however, instantaneous, and as a result, the reactions of the crew or aircraft may not be sufficient. It is possible for the effects of wind shear to exceed the pilot's capabilities or performance of the aircraft. (14:8)

The above procedures and equipment developments are designed to help predict and detect LLWS. However, they can only warn of its dangers, and provide little guidance to pilots on how to cope with it. The next chapter is designed to help aircrews control and cope with the LLWS hazard.

Chapter V

HOW TO CONTROL AND COPE WITH LOW LEVEL WIND SHEAR

This chapter will supply the final missing link in the solution to the LLWS problem for aviators. This missing link is the ability to control and cope with LLWS hazards. Chapters two and three provided the information necessary for aviators to understand the effects and causes of LLWS. Chapter four described the scientific research providing the technology to better predict and detect LLWS hazards. However, the aviator still must be able to utilize all this information to ensure safety of flight when confronted with LLWS hazards.

First, this chapter will document that both civilian and military agencies have stipulated that this final link is essential for solving the LLWS problem. Then an explanation of why technology alone is not a solution will be given. Only pilots have the ultimate responsibility to ensure safety of flight, and safety of flight is a product of sound pilot judgment. Finally, proven techniques and procedures for coping with LLWS will be given to be used when avoidance is not possible. Mastering these proven techniques and procedures will assist pilots in developing sound pilot judgment for coping with LLWS.

An August 1983 study conducted by the National Academy of Sciences - the study was mandated by the U.S. Congress - concluded that most pilots are not adequately trained to cope with wind shear situations(9:62). The study also concluded that "an education campaign directed at all classes of pilots" offers the nearest-term prospect of reducing the risk of low level wind shear hazards. Finally, the study recommended that the FAA develop and implement a coherent and sustained program for coping with the educational, meteorological, technological, and operational aspects of LLWS hazards. (9:62-63)

The United States Air Force conducted a wind shear conference at Travis AFB, California, in May of 1978(11:8). There were two purposes for the USAF conference: (1) determine the fundamental questions on how to cope with wind shear hazards; and (2) develop an Air Force education program for understanding and coping with wind shear hazards(11:8). The conference attendees concluded that the hazards associated with wind shear during the takeoff and landing phases of flight are not fully understood by USAF crew members, and those who do understand the hazards don't know how to cope with LLWS hazards(11:8-9).

That technology alone will not solve the LLWS problem was demonstrated vividly by the crash of Boeing Flight 759 at the New Orleans International Airport on 9 July, 1982(10:32). The New Orleans airport had a low level wind shear alerting system(LLWSAS) installed at the time of the accident. However, even with warnings of possible LLWS, pilots are not prohibited from taking off or landing. In this case the LLWSAS was malfunctioning and the pilot did not actually receive a warning. However, the pilot was aware of numerous indications that LLWS was probably present on the departure path. There were reported thunderstorms in the area as well as reports of shifting winds and heavy rains. Despite the fact he was flying a vulnerable aircraft, being very heavily loaded and in a very warm temperature, the pilot was exonerated from blame when he initiated the takeoff. In times past the National Transportation Safety Board(NSTB) would most probably have found the cause, or at least a contributing factor, the pilot's decision to takeoff in the conditions that existed. But this one was charged, in effect, to an act of God. (2:34)

Does the large amounts spent on wind shear and thunderstorm forecasting and detection systems by the Federal Government relieve pilots from their primary responsibility for safety of flight? Some people might answer yes to this question after reading the NSTB findings on the Flight 759 crash at New Orleans(2:34). The New Orleans crash of Flight 759 could have been avoided. The crew had all the warning signs of danger from LLWS, but they erred on the side of optimism in interpreting them. Optimism is habitual in pilots; it is a requirement of the trade(4:92). But some people are bound to wonder. If the pilot knew that there was a risk, would it not have been reasonable to expect him to delay the takeoff until the weather changed? Experienced pilots are aware that one airplane may encounter a ferocious downdraft or shear on final approach, and another, 90 seconds behind it, may find only smooth air. They inevitably develop a somewhat casual attitude about hazards that are difficult to pin down or to avoid. The ruling inclination of pilots is to launch unless the contra-indications are really overwhelming - which usually means, unless nobody else is launching. Few pilots have the fortitude to hang back when everybody else is taking off. There is probably an element of competitive spirit involved, too; if the other guy can do it, I can. (4:95)

The underlying motive is practical. If pilot's didn't fly when there was bad weather - snow, ice, wind, or thunderstorms - then they couldn't be a professional pilot. Those are all elements that professional pilots have been called upon to deal with ever since airplanes were invented. The military pilot is driven by his mission or fear of ridicule. Perhaps unconsciously, the customers of airlines have accepted a certain level of risk in exchange for the convenience of fast travel. This risk is similar to what city dwellers accept such as pollution, collision, mugging and murder in exchange for employment, company, or a wider choice of entertainment(4:95). Pilots are, by and large, people who have adapted to that low , but unavoidable level of risk-taking, and are neither too cautious nor too bold for the comfort of their clients or their employers.

However, it is important to recognize that dealing with wind shear, as with so many other things in flying, is an individual effort. No Government employee "helps" us fly or make the decisions that lead to a safe flight. They give information and issue clearances that we fly. But they don't advance power for takeoff. Anything that is done to encourage a pilot to feel less than fully responsible for the safe conduct of a flight can only be detrimental to safety. There is self-deception in a finding that a pilot is a victim of something other than his own judgment. The risks of aviation are very clearly defined. There is no question that we are better equipped to deal with thunderstorms and LLWS now than at any time in the past, thanks to new technology. However, the ultimate responsibility for safety of flight must still be based on pilot judgment. (2:34)

Therefore, the ultimate solution to control the LLWS hazard is to avoid its encounter when possible. Pilots have the primary responsibility for making this avoidance decision. They must be aware of the effects and causes of LLWS and be ever alert to indications of its presence. This knowledge and awareness can provide the tools for sound pilot judgment in making avoidance decisions. However, what can be done in those situations where LLWS must be encountered? The answer to this question is the subject of the rest of this chapter.

Before describing specific techniques and procedures for coping with wind shear, a general review of the effects of wind shear on an aircraft is necessary. Wind shear is a result of a change in direction and/or velocity of wind. An aircraft is affected by this change because the aircraft motion relative to the ground is also changed by the wind. Changes in energy cause changes in aircraft position and speed. In unaccelerated flight an aircraft maintains a certain energy level, balanced against the surrounding atmosphere. If this balance is disturbed, by a wind shear, for example, some compensation must be made. Events in an aircraft are dynamic, and the aircrew is continually reacting to the changing flight conditions. Changes in wind velocity or direction are part of these dynamic conditions. The crew perceives the need for a change in aircraft energy levels through the instruments and makes changes. The applied corrections are not, however, instantaneous, and as a result, the reactions of the crew or aircraft may not be sufficient. It is possible for the wind shear to exceed the pilot's capabilities or performance of the aircraft. (14:8)

The techniques or procedures available for coping with LLWS depend on the class of wind shear encountered. These two classes of wind shear were described in chapter two as vertical and horizontal wind shears. The big difference between the two is the time available for the pilot and aircraft to make adjustments. The two types are not separate and independent, but from the pilot's standpoint they present different problems and require different reactions. Vertical shears are more serious and occur mostly in association with thunderstorms and fronts. The most serious type vertical shear is the microburst because of its violent downburst and insidiousness. The pilot and aircraft have less time to make adjustments in a vertical shear encounter. Therefore, first techniques and procedures for coping with vertical gusts will be discussed. Then, finally, the more frequent, but less dangerous horizontal wind shear encounter will be addressed.

Over the years two distinct schools of thought have evolved on how to optimize aircraft performance during a chance encounter with a microburst. Note that the microburst is only one of several types of vertical shears, but is the most serious. Therefore, even though the techniques and procedures given here are specifically for coping with microbursts, they will suffice for all vertical shears. (16:10)

One technique involves flying out at the minimum drag speed, while the second is called the "stick shaker" method. The determining factor in choosing which method to employ appears to be primarily a function of where the aircraft is in relation to the ground, and whether long or short term climb performance is required. However, since the second method, stick shaker, is the only one recommended by this analysis the other method should only be studied to understand why its use is dangerous. (16:10)

The first technique is known as flying at minimum drag speed. Many pilots have been trained to lower the nose to pick up airspeed when it is falling off. In a wind shear situation this could be fatal, because too much potential energy was traded for kinetic energy. When the tailwind generated by the downdraft is encountered lift will be lost(12:42). During microburst conditions, a potentially deadly situation exists in which an aircraft may be robbed of essential indicated airspeed to the point where it's now below the approach, departure or minimum drag speed. As pilots, we're often more concerned with loss of airspeed than flight path control. Furthermore, we have little or no awareness of the effects that a dramatic change in AOA can have. (16:10)

However when encountering microburst conditions near the ground, lowering the nose of the aircraft results in a further, more critical reduction in AOA, a significant loss of altitude, a degradation in climb performance and ground impact. The favorable alternative would be to apply maximum thrust while smoothly increasing pitch attitude until the descent is arrested or a stick shaker condition is reached(16:10). By way of explanation, stick shaker speed is indicated in many aircraft by a warning horn or by the yoke or stick actually shaking. This phenomenon is built into the aircraft to give the pilot a warning above stall speed. Other aircraft without this built-in warning system can use initial buffet speed as essentially the same speed. These speeds, stick shaker and initial buffet speed, are speeds some 10 to 15 knots above stall speed and provide a small margin of safety. (16:10)

In applying the stick shaker method, the pilot must be able to accept the fact that the aircraft will fly safely at speeds below climb or approach speeds(6:18 - 19). When encountering LLWS the pilot must be more concerned with flight path than airspeed. He must apply full thrust and increase pitch until the the descent is arrested to avoid ground impact. Only after safely above the ground with a climb situation established should airspeed be allowed to accelerate. (16:19) Pitch during this maneuver may exceed the maximum pitch attitude normally recommended during a missed approach or takeoff. If this slow speed climb regime is exercised, however, it may provide the additional performance required to avoid ground impact. Airspeed, again, can be traded down to shaker speed(kinetic energy for potential energy), if available, when short term climb performance is required. (16:19)

A workshop conducted by National Aeronautics and Space Administration in 1982 recommended the use of this stick shaker flyout method for pilots who encounter low level wind shear(12:42). The pilot should use a strategy of flying the aircraft at its optimum performance configuration - maximum lift/drag - until surface impact is imminent(12:42). Then, the pilot will have enough excess energy, between maximum lift/drag and stall, to trade in order to flare and soften ground impact(12:42).

The workshop and the FAA propose trading speed off to the optimum lift/drag position and leaving enough speed above stall for flare if a crash becomes imminent. Participants in the workshop also concluded that wind shear is difficult to simulate because of the differences in size, severity, and duration. They said data on wind shear situations indicate that some are so severe they cannot be safely penetrated. (12:42)

Under severe microburst flight conditions, IAS is an inferior and invalid parameter for adequately deciphering the entire aerodynamic picture. Consequently, the indiscriminate chasing of IAS as an escape maneuver, without cross-referencing other instrumentation, can, in and of itself, kill(16:11). Therefore, a more valid indication of stick shaker speed would be to use angle-of-attack(AOA) if available(16:11).

These AOAs should closely correspond to the minimum drag line(AOA, not IAS) where thrust available exceeds thrust required by the largest margin, thereby producing the greatest possible inertial acceleration in the upward plane. This technique should provide positive lift generation slightly in excess of and then nearly equal to weight. Optimizing all the physical forces of flight and precision control of angle of attack are important keys to success during this critical phase of flight. This assumes, of course, that the given aerodynamic capability of the aircraft can exceed the physical forces of the shear or microburst. This is a dynamic condition requiring continuous adjustments in attitude until steady flight conditions are regained. (16:11)

During microburst flight, there exists a critical limit beyond which the point of recovery is clearly passed. When the pitch attitude has been reduced(even a few degrees), or the AOA has been reduced to near zero or some negative value, the aircraft experiences less than one G flight. Analysis of past mishap flight recorder data reveals that approximately .75 G or less typically exists for several seconds during this transition. During this period, any rate of climb then deteriorates into a rate of descent. This is an indication the AOA has been severely reduced and lift generation is now significantly less than weight. These conditions produce an unbalanced force with a resultant downward vector component and in turn, accelerates the aircraft with an increasing, downward vertical velocity. This inevitably results in ground impact! During this latter phase, IAS may even register an increase due to acceleration. (16:11)

It is imperative to maintain a minimum of one G flight and avoid the development of a descent rate. If a positive climb rate can't be initially maintained or achieved, attempt to fly out in at least level flight condition. Once this downward acceleration has developed, it requires an extraordinary force to overcome, one which is nearly impossible for an energy deficient aircraft to generate, especially when given very limited time and altitude constraints. (16:11)

The solution to the wind shear threat can be found in the precision control of the relative wind through AOA and the optimizing of all the physical forces of flight. So, if ever confronted with a microburst near the ground, the best chance of surviving lies in applying maximum thrust(and executing a missed approach), while: (1) rotating to the AOA for maximum lift generation to discontinue or prevent a downward vector and, once level flight or positive climb rate is attained, then; (2) flying out at AOA for best angle of climb until a positive rate of climb is established and obstacles are cleared; and finally (3)accelerating to the AOA for best rate of climb. (16:11)

Next, the more frequent, but less dangerous horizontal wind wind shear encounter will be addressed. The updrafts and downdrafts beneath a thunderstorm produce vertical shears that have obvious effects on an aircraft: up and down! However, since flying regulations prohibit takeoffs and landings beneath thunderstorms, the shear aviators are most likely to encounter is a horizontal shear. Its effect on an aircraft may not be so obvious. Generally, there are only two types of horizontal wind shears: an increasing headwind; and a decreasing headwind. Many writers refer to these two types of shears as headwind to tailwind, and tailwind to headwind situations. However, the normal situation is only to takeoff or land into the wind. Therefore, all cases fit into one of the two categories: an increasing or decreasing headwind. (5-78 -79)

For pilot purposes, a sudden change in the headwind on final means a sudden change in indicated airspeed. A sudden change in the wind over an airfoil causes a sudden change in lift. An increase in the headwind causes an increase in lift, and vice versa. Two examples will show what happens when a headwind is suddenly increased or decreased 20 knots. (19:22 - 23)

In the first example an aircraft flying a final approach at 140 knots IAS encounters a 20 knot increase in headwind on final. What would happen to this nicely trimmed aircraft? The nose would pitch up, VVI would shallow out, and the aircraft would go above glide slope.

In the second example, the aircraft is flying the same final approach at 140 knots IAS, but this time encounters a headwind decrease of 20 knots. What would happen? The indicated airspeed would drop 20 knots, the nose would pitch down, the VVI would increase, and the aircraft would go below the glide slope.

What caused each aircraft to react the way it did? The answer is that a sudden change in the wind over an airfoil causes a sudden change in lift. An increase in the headwind causes an increase in lift and vice versa. But aircraft are designed to be stable. An aircraft trimmed for 140 knots that experiences change in airspeed will seek 140 knots. An aircraft trimmed for 140 knots that is suddenly indicating 160 knots will pitch up to seek 140 knots. An aircraft trimmed for 140 knots that now indicates 120 knots will pitch down to seek 140 knots. (20:14 - 15)

Therefore, an aircraft reaction to horizontal wind shear is summarized below(19:22 - 23 ;20:14 - 15,30).

AIRCRAFT ACTION AND PILOT REACTION TO HORIZONTAL SHEAR:

Increasing Headwind: (See figure 2 on next page)

Aircraft Reaction: When an aircraft flies through a shear where the headwind component increases, this is what happens: indicated airspeed increases by the amount of the shear value; lift increases, causing the aircraft to pitch up and go above glide path. (Next text on page 37)

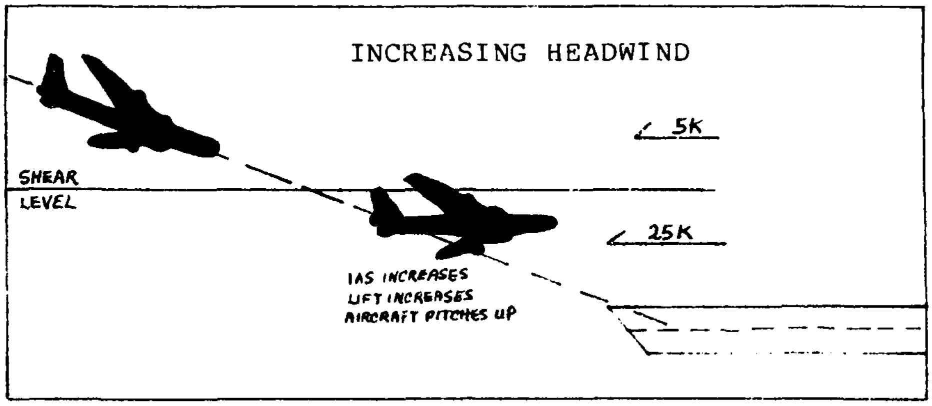


FIGURE 2

When an aircraft flies through an increasing headwind shear the indicated airspeed increases by the amount of the shear value, and lift increases which causes the aircraft to pitch up and go above glide path.

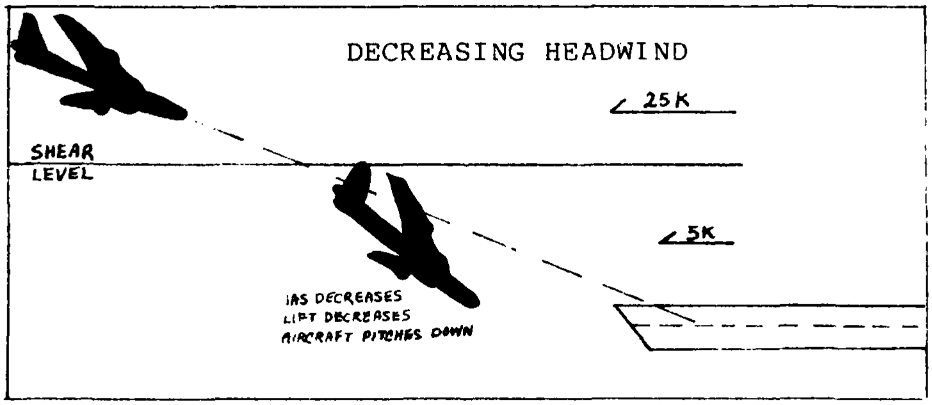


FIGURE 3

When an aircraft flies through a decreasing headwind shear the indicated airspeed decreases by the amount of the shear value, and the lift decreases causing the aircraft to pitch down and go below the glide path.

Pilot Reaction: The pilot sees an increase in airspeed and the aircraft going high on the glide path. The ingrained pilot response is to reduce power and nose over to return to the glide path. When the aircraft returns to the glide path, new performance requirements are necessary. So the pilot now needs to make a second power change which will be larger than the first correction. The pilot must add more power than was pulled off to restabilize on the glide slope. The explanation for this need for a larger power requirement for the second change is inertia. An aircraft has a certain amount of inertia built up as it moves through the air. Indicated airspeed changes instantaneously, but ground speed doesn't. (20:14)

Decreasing Headwind: (See figure 3 on previous page)

Aircraft Reaction: When an aircraft flies through a decreasing headwind shear, this is what happens: indicated airspeed decreases by the amount of the shear value; lift decreases, causing the aircraft to pitch down and go below the glide slope.

Pilot Reaction: The pilot reacts to the drop in airspeed and the aircraft going below the glide path by increasing pitch and adding power. When the aircraft returns to the glide path, new performance requirements are necessary. The second change requires less power to be pulled off than was added in the first change, once again because of inertia. The second correction must be larger than the first one or the aircraft will over-correct. Wind shear is a two act play! You have to make one correction to get back on glide path, then make a second, larger correction to stay there. (20:15,30)

The decreasing headwind is a decreasing performance situation and is therefore the most dangerous. Can you safely fly through a decreasing performance shear? The answer is yes, if you have enough energy. An aircraft can gain kinetic energy by one of three ways: (1) add thrust, but the problem with this option is spool-up time; (2) trade potential energy(altitude) for kinetic energy(airspeed), but when close to the ground, this may not be a viable option; and (3) pad the airspeed. (19:22)

Using "ground speed" as a reference during an approach when wind shear is suspected is important because it insures flying airspeed at all times, even in abrupt wind shear situations. Ground speed as a parameter is a radical departure from the school of thought that says a stabilized and constant IAS with very small power changes will result in the best precision approach. Under wind shear conditions the latter technique can result in a severe energy deficiency with catastrophic results. The ground speed technique is a relatively new concept in airmanship. It may require abrupt power changes, and accepts relatively radical IAS changes, and accompanying aircraft attitude changes to maintain a minimum ground speed; hence, the kinetic energy to allow the aircraft to experience a sudden loss of IAS but still have sufficient flying speed to maintain safe flight. (22:2 - 3)

The technique is to compare an "over the fence" ground speed using the reported surface winds and then fly the approach at that ground speed, or faster if required, but never slower. This means there are now two minimum approach speeds to worry about: a minimum IAS, and a minimum ground speed(the computed "over the fence" ground speed). Therefore, the speed to fly on final will be the higher of either the IAS or the "over the fence" ground speed computed. For people who have INS, doppler or other ground speed indicators, the "over the fence" ground speed is simply read off the indicator. For all others the "over the fence" ground speed must be calculated. This is done by the following formula: VVI readout when stabilized on glide slope divided by descent gradient to maintain a no-wind glideslope equals ground speed in nautical miles per minute(NM/Min). (22:2)

There is a direct relationship between ground speed and the VVI when the aircraft is stabilized on the glide path. Next, this relationship will be examined. A three degree glide slope descends 318 feet per nautical mile. For every nautical mile we track over the ground, the aircraft must descend 318 feet in order to stay on the glide slope. For a ground speed of two NM per minute, the VVI will be 2 X 318 = 636 feet per minute. So when stabilized on glide slope divide VVI readout by 318(or 265 for a 2 1/2 degree glide slope) to get ground speed in NM per minute and then multiply by 60 to get ground speed in knots. Time out! Even though all of the above may be accurate, it may be too cumbersome to be useful to the pilot in the cockpit. What he can use is a simple method that will give a good approximation of ground speed while on the glide slope. (22:2 - 3)

The following is such a method. AFM 51-37 requires the determination of an initial descent rate for all approaches(28:3-4;28:3-8). The easiest way to do that is by using the Rate of Descent Table in the front of the

Instrument Approach Procedures Books. (See figure 4 below for table) But looking at the Rate of Descent Table shows that the table can also be entered with descent angle and VVI to get actual ground speed. Therefore, a three-step approach can be used to compute "over the fence" ground speed: (1) determine expected VVI using above mentioned table; (2) use actual VVI to get ground speed from the same

INSTRUMENT APPROACH PROCEDURE CHARTS RATE OF DESCENT TABLE (ft. per min.)								
	GROUND SPEED(knots)							
GLIDE SLOPE	90	105	120	135	150	165	180	
2.0	320	370	425	475	530	585	635	
2.5	395	465	530	595	665	730	795	
3.0	480	555	635	715	725	875	955	
3.5	555	650	740	835	925	1020	1110	

FIGURE 4

table; and (3) adjust airspeed, if required to the newly computed required ground speed. (22:2 - 3)

Finally, the following recommended techniques are given to help cope with LLWS situations:

*<u>Increasing Headwind</u>: Performance increasing situation is created here. (21:19)

**<u>Takeoff Procedures</u>: Takeoff into an increasing headwind shear is no problem as performance is increasing.

**<u>Landing Procedures</u>:

***Do not pad approach speed. If shear exists, indicated airspeed and lift will increase.

***If shear is close to the ground(past decision height), it might cause a long, hot landing. Go around, if unable to land in touchdown zone.

***If shear is encountered at a higher altitude, resist the temptation to make a large power reduction. Accept higher indicated airspeed and use pitch and trim to get back to glide path, if possible. But avoid large trim changes.

***Avoid high descent rates with the engines spooled down. If you can't restabilize on glide path, go around.

*Decreasing Headwind: Decreasing performance situation exists here, as ground speed is lower than reference ground speed. (21:19)

**Takeoff Procedures:

***Delay takeoff, if possible.

***Pad rotate and climbout airspeeds, runway and obstacles permitting.

***If unable to delay takeoff, let airspeed build as soon as possible after takeoff and delay flap retraction until the upper limits of the flap retraction schedule.

**Landing Procedures:

***Pad approach airspeed by the amount of the shear potential.

***Be aware of stopping distance. This should rarely be a limiting factor, considering the length of SAC runways and normal landing gross weights. However, watch with low RCRs.

***Monitor ground speed. If it increases gradually(no shear exists), then anticipate the need to reduce power and increase descent rate in the final part of the approach.

***Avoid high descent rates with engines spooled down.

***If a go around is necessary, use full thrust. Don't be shy!

Finally, the above procedures and techniques when applied with sound pilot judgment should provide guidance for coping with low level wind shear. However, when possible, low level wind shear should always be avoided because of its dangerous and unpredictable effects.

Chapter VI

SUMMARY

The scissorslike action of two air masses moving in relation to one another can be very hazardous to large, heavy jet aircraft. This phenomena is called low level wind shear when it occurs below 2,000 feet AGL. From 1965 to 1974, the Air Force experienced 41 probable wind shear/vortex related aircraft accidents - the total price tag was 18 million dollars. This illustrates the need for an education program for crew members on low level wind shear(LLWS) hazards. The purpose of this lesson plan is to teach crew members to understand, recognize, and cope with low level wind shear hazards.

Factors having a bearing on the effects of LLWS are: aircraft configuration; aircraft speed; aerodynamic characteristics; power/weight ratio; engine response time; and the ability of the flight crew to respond. The general effect of LLWS is to modify normal pitch and power requirements used in aircraft ascent and descent profiles. The modifications to aircraft profiles caused by LLWS depend on the type shear encountered. Horizontal shears are less dangerous because the velocities and rates of change are usually small enough to permit aircraft and pilots to adjust safely. A more serious and only recently appreciated aspect of the LLWS problem is vertical shears. Vertical shears are much smaller and more dangerous because the velocity gradients within the burst are steeper, and the aircraft and pilot have less time to make adjustments.

The meteorological phenomena causing LLWS are primarily: (1) thunderstorms; (2) warm and cold fronts; (3) land/sea breezes; (4) occasionally, mountain waves; and (5) less frequently, low level inversions. Thunderstorms are by far the most hazardous due to the severity, complexity, and multiplicity of the shears produced. The wind shear hazards associated with thunderstorms can be grouped into four categories based on size, duration, and effects. These four categories are: (1) high based cumulus clouds; (2) first gusts; (3) large downbursts; and (4) microbursts.

In addition to thunderstorms, certain frontal systems are the most prominent cause of significant low level wind shear hazards. Winds can be significantly different in the two air masses which meet to form a front. Both warm and cold fronts cause LLWS. Wind shear caused by warm fronts is more dangerous because of more intense shear and the frequent low ceilings and visibilities associated with warm fronts. Warm frontal wind shear may persist six hours or more over an airfield ahead of the front because of the front's shallow slope and slow movement. Cold fronts are usually less dangerous because normally the danger area is of shorter duration and no low visibilities are present. Because cold fronts have a greater slope and normally move faster than warm fronts, the duration of LLWS is usually less than two hours, and occurs after frontal passage.

The other three causes of LLWS are less frequent, but still can produce significant hazards. Land/sea breeze LLWS is caused by differences in temperature between land and adjoining water. Mountain wave LLWS is caused by the funneling effect of high terrain which accelerates the wind and spills it into the flight path of aircraft. Finally, low level inversions can cause LLWS when overnight cooling creates a temperature inversion in conjunction with the low level jet.

Recognition and detection of LLWS is very important and is a prerequisite to coping with the hazard. Technology has been developed to assist the air crew in both ground and airborne detection. New radars for ground and airborne use are being developed which will give the air crew warning of the presence of LLWS. However, at present this new technology is still in the developmental stage. Therefore, the air crew must still rely on pilot judgment with imputs from preflight weather briefs, pilot reports, inflight weather service, air traffic control, and aircraft instruments for LLWS detection.

The best way to cope with severe LLWS is to avoid it when possible. However, this is not always possible. Using "ground speed" as a reference during approach when wind shear is suspected is important because it insures flying airspeed at all times, even in abrupt wind shear situations. The groundspeed technique is a fairly new concept in airmanship, and may require abrupt power and attitude changes. Also, utilizing minimum drag configurations during departure and approach will aid in acceleration should LLWS be encountered.

When encountering microburst conditions near the ground, lowering the nose of your aircraft results in a further, more critical reduction in angle-of-attack, a significant loss of altitude, a degradation of climb performance and ground impact. A more favorable alternative would be to apply maximum thrust while smoothly increasing pitch attitude until the descent is arrested or a stick shaker condition is reached.

BIBLIOGRAPHY

A. REFERENCES CITED

ARTICLES AND PERIODICALS

1. Blatter, Richard W. "Spearheads and Downbursts," Combat Crew, March 1977, pp. 8-11

2. Collins, Richard L. "Act of God? or Man?" Flying, August 1983, p. 34.

3. "Downbursts," The MAC Flyer, April 1978, pp. 12-14.

4. Garrison, Peter. "Aftermath: Dark Day at New Orleans," Flying, August 1983, pp. 92-95.

5. Garrison, Peter. "Shear Determination," Flying, February 1983, pp. 77-80.

6. Higgins, Paul R. and Donald H. Patterson. "More About Wind Shear Hazards," Aerospace Safety, March 1979, pp. 14-21.

7. "Hot & Dry Windshear," Aerospace Safety, October 1977, pp. 10-11.

8. Johnson, David E. "Low level Wind Shear," Aerospace Safety, October 1979, pp. 1-3.

9. Klass, Philip J. "Avionics: Training Key to Wind Shear Effects," Aviation Week & Space Technology, January 2, 1984, pp. 62-63.

BIBLIOGRAPHY

10. Kozicharow, Eugene. "NTSB Cites Wind Shear in New Orleans Accident," Aviation Week & Space Technology, March 28, 1983, p. 32.

11. Lawrence, James J. "USAF Wind Shear Conference," Aerospace Safety, July 1978, pp. 8-9.

12. Mordoff, Keith F. "Aeronautical Engineering: Researchers Study Methods to Combat," Aviation Week & Space Technology, February 2, 1983, pp. 40-42.

13. Most, Bruce W. "On the Track of Deadly Wind Shear," Popular Science, May 1983, pp. 78-80.

14. Richardson, John E. "Shear Distress," Aerospace Safety, April 1978, pp. 8-10.

15. Richardson, John E. "Wind Shear," Flying Safety, August 1981, pp. 4-7.

16. Towers, Joseph F. "Blueprint for Disaster," The MAC Flyer, October 1983, pp. 8-11.

17. Towers, Joseph F. "Wind Shear: Mother Nature at Her Worst," The MAC Flyer, June 1982, pp. 4-6.

18. Walters, Tome H., Jr. "Wind Shear for the Line Pilot," Combat Crew, March 1980, pp. 26-27.

19. Walters, Tome H., Jr. "Wind Shear: Part II, How Aircraft React to a Shear," Combat Crew, April 1980, pp. 22-23.

BIBLIOGRAPHY

20. Walters Tome H., Jr. "Wind Shear: Part III, Increasing Headwind and Decreasing Headwind," Combat Crew, May 1980, pp. 14-30.

21. Walters Tome H., Jr. "Wind Shear: Part IV, Reference Ground Speed," Combat Crew, June 1980, pp. 18-19.

22. White, Dan, et al. "Wind Shear," Aerospace Safety, August 1978, pp. 1-3.

23. "Wind Shear: A Year-round Hazard," The MAC Flyer, November 1979, pp. 6-7.

24. "Wind Shear: Progress, But No Solution," Science News, September 3, 1983, p. 151.

OFFICIAL DOCUMENTS

25. National Severe Storm Laboratory. Gust Front Analytical Study by R.C. Golf, J.T. Lee and E.A. Brandes. Norman, Oklahoma, December 1977.

26. United States Congress. House. Committee on Science and Technology. Subcommittee on Investigations and Oversight. Aviation Weather, Hearing before the Subcommittee on Investigations and Oversight and the Subcommittee on Transportation, Aviation, and Materials of the Committee on Science and Technology U.S. House Representatives, Ninety-Seventh Congress, Second Session, August 11, 1982, Washington, D.C.: Government Printing Office, 1982.

27. U.S. Department of the Air Force. General Flight Rules. AF Regulation 60-16, Washington,

BIBLIOGRAPHY

D.C.: Government Printing Office, 5 December, 1980.

28. U.S. Department of the Air Force. Instrument Flying. AF Manual 51-37, Washington, D.C.: Government Printing Office, 15 August, 1979.

29. U.S. Department of the Air Force. Strategic Air Command. SAC Instrument Flight Center Curriculum SAC Regulation 51-37. Washington, D.C.: Government Printing Office, 21 September, 1984.

30. U.S. Department of the Air Force. Weather for Aircrews, AF Manual 51-12, Vol 1. Washington D.C.: Government Printing Office, 1 January, 1982.

B. RELATED SOURCES

ARTICLES AND PERIODICALS

Allen, Robert H. "Weather Radar," The MAC Flyer, September 1981, pp. 12-13.

Brownfield, Orlen L. "Wind Shear for Pilots," The MAC Flyer, May 1978, pp. 4-6.

Bulloch, Chris. "NEXRAD When?" Interavia, September 1982, pp. 961-962.

Carter, David C. "Some Comments on Wind Shear," Aerospace Safety, February 1977, pp. 10-12.

BIBLIOGRAPHY

Christensen, David. "An Inquiry into Wind Shear," Combat Crew, July 1979, pp. 14-21.

Kopp, Robert W. and John J. Richard. "Plane Facts About Takeoffs," Combat Crew, April 1984, pp. 9-11.

Richardson, John E. "Wind Shear, Part II," Flying Safety, September 1981, pp. 18-20.

"Wind Shear Dangers," Pacific Defense Reporter, August 1982, p. 49.

Walters, Tome H., Jr. "Compensating for Winds," Combat Crew, August 1979, pp. 14-15.

OFFICIAL DOCUMENTS

Air Force Cambridge Research Laboratories. Doppler Radar Investigation of Flow Patterns Within Thunderstorms by Michael J. Kraus, Hanscom Field, Massachusetts, 26 June 1974.

Air Force Geophysics Laboratory. Real Time Warning Utilizing Doppler Velocities From a Color Display by Carlton L. Bjerkaas and Ralph J. Donaldson, Jr., Hanscom AFB, Massachusetts, 10 March, 1978.

National Transportation Safety Board. Bureau of Aviation Safety. Aircraft Accident Report. Allegheny Airlines, Inc., Douglas DC-9, N994VJ, Philadelphia, Pennsylvania, Washington D.C.: Government Printing Office, 19 January, 1978.

BIBLIOGRAPHY

National Transportation Safety Board. Bureau of Aviation Safety. Aviation Accident Report. Continental Air Lines, Inc., Boeing 727-224 N32725. Tucson, Arizona, June 3, 1977, Washington D.C.: Government Printing Office, 1 August, 1978.

National Transportation Safety Board. Bureau of Aviation Safety. Aircraft Incident Report. Eastern Airlines, Inc., Boeing 727-25 N8139. Atlanta Hartsfield International Airport, Atlanta, Georgia, 22 August, 1979. Washington D.C.: Government Printing Office, 28 May 1980.

National Transportation Safety Board. Bureau of Aviation Safety. Revised Aircraft Accident Report. Pan American World Airways, Inc., Boeing 707-321B N454PA, Pago Pago, American Samoa, 30 January, 1974. Washington D.C.: Government Printing Office, 6 October, 1977.

APPENDICES

APPENDIX

APPENDIX A

VERIFICATION PLAN

The following two examinations are designed to validate this lesson plan and provide feedback to the SIFC instructors. The two exams each cover all areas and should be given on a rotating basis to the students. All examination questions are taken from the contents of this lesson plan. Of course, the examinations will need to be updated on a continuing basis. References and answers for all questions in this verification plan will be found at the end of each examination.

APPENDIX A

TEST # 1

MULTIPLE CHOICE

1. Which of the following is the best definition of "wind shear?"

A. The "shearing" or "scissorslike" action of two air masses moving in relation to one another.

B. The turbulence resulting when a vertical and horizontal air mass come together.

C. Gusty wind resulting from the interaction of two or more air masses coming into contact.

D. Shear occurring only between the surface and 1,500 feet AGL.

2. Which of the following statements about LLWS is <u>not</u> true.

A. Light airplanes normally have no difficulty in making rapid airspeed adjustments and, therefore, have less problems with LLWS.

B. For heavy aircraft and ones that take time to accelerate to their best climb speed, the greatest hazard of LLWS is during approach.

C. The effect of LLWS is to modify normal pitch and power requirements used in aircraft ascent and descent profiles.

D. Airplanes that are heavily loaded or draggy and that can't make rapid airspeed accommodations usually have the most serious problems with LLWS.

3. All of the following, <u>except one</u>, are factors that have a bearing on the effects of wind shear.

A. Ability of the flight crew to respond.

B. Aircraft speed and engine response.

C. Aircraft aerodynamic characteristics and aircraft configuration.

D. Downbursts and microbursts.

4. Wind shears can be divided into which of the following general classes?

A. Large and small.

B. Steep and shallow.

C. Horizontal and vertical.

D. Updrafts and downdrafts.

5. Which of the meteorological phenomena causing LLWS is considered the most dangerous?

A. Warm fronts.

B. Microbursts.

C. Low level inversions.

D. Cold fronts.

6. All of the following, except one, are good indications of LLWS being present from high based cumulus clouds.

A. Very dry surface air with a dew point spread of 35 degrees F or more.

B. Temperature warmer than 75 degrees F.

C. High based cumulus type clouds with Virga present.

D. Strong winds from the ground to the cloud bases.

7. Which of the following is not true concerning "first gusts?"

A. First gusts are associated with mature thunderstorms and are the result of large updrafts which spread out vertically.

B. Is a rapid shift and increase in wind just before a thunderstorm hits.

C. The gust wind speed in first gusts may increase as much as 50 percent between the surface and 1,500 feet.

D. First gusts winds can change direction by as much as 180 degrees and reach velocities of 100 knots as far as 15 miles ahead of the storm.

8. An extremely intense localized downdraft ranging in size from four to 20 km and lasting from five to 20 minutes is a ________.

A. Microburst.

B. Macroburst or large downburst.

C. First gust.

D. Mature thunderstorm.

9. Which of the following is <u>true</u> concerning a "macroburst"or large downburst?

A. They are usually further from the thunderstorm than the first gust.

B. Dust clouds, roll clouds, or intense rainfall are indications of its presence.

C. Produces downbursts that can exceed aircraft climb capabilities of light non-jet aircraft only.

D. Are usually .25 to 2.5 miles in diameter and two to 10 minutes in duration.

10. Which of the following categories of LLWS hazards caused by thunderstorms is the <u>most</u> insidious?

A. Macrobursts.

B. First Gusts.

C. Frontal winds.

D. Microbursts.

11. Which of the following is <u>not</u> true concerning "microbursts?"

A. Microbursts range in diameter from .25 to 2.5 miles.

B. Microburst duration is usually from two to 10 minutes.

C. Microbursts have only recently been identified(since the mid-1970s).

D. Microbursts are not considered too dangerous since they are a rare meteorological event.

12. Which of the following are accurate indications of warm fronts that indicate the presence of LLWS?

A. Relatively steep slope.

B. Restricted visibility is also usually behind the frontal passage.

C. Shear will reach the airfield 6-12 hours <u>before</u> warm frontal passage at the surface.

D. Shear will reach the airfield 6-12 hours <u>after</u> warm frontal passage at the surface.

13. Which of the following are <u>not</u> accurate indications of LLWS caused by cold fronts?

A. Relative steep slope.

B. LLWS will occur 30 minutes to one hour <u>before</u> frontal passage at the field.

C. LLWS will occur 30 minutes to one hour <u>after</u> frontal passage at the field.

D. Restricted visibility is behind the front.

14. Which of the following is <u>not</u> a cause of LLWS?

A. Low level jets over radiation inversions.

B. Land/sea breezes.

C. Mountain waves or funneling winds.

D. Turbulence.

15. Which of the common causes of LLWS is least likely to be a problem?

A. Low level inversions.

B. Fronts.

C. Thunderstorms.

D. Turbulence.

TRUE OR FALSE QUESTIONS

Circle the most correct answer of the following questions.

T F 1. Low level wind shear is a problem for small aircraft, but not for large jets.

T F 2. Low level wind shear is easy to compensate for if you are aware of its existence.

T F 3. You should suspect LLWS around a frontal zone, even if there is no weather associated with the front.

T F 4. LLWS can be associated with rain showers as well as with thunderstorms.

T F 5. The most hazardous LLWS is always preceded by turbulence.

T F 6. LLWS is normally more hazardous around warm fronts than it is around cold fronts.

T F 7. Wind cannot affect an aircraft once it is flying except for drift and ground speed.

T F 8. The effect of LLWS is to modify normal pitch and power requirements used in aircraft ascent and descent profiles.

T F 9. The differential heating and cooling of land and sea surfaces can cause LLWS.

T F 10. LLWS is only dangerous during the landing phase.

APPENDIX A

ANSWERS TO EXAMINATIONS

EXAM # 1

MULTIPLE CHOICE:

QUESTION #	ANSWER	REFERENCE PAGE
1.	A	3
2.	B	4
3.	D	4
4.	C	4
5.	B	9
6.	D	7
7.	A	7
8.	B	8
9.	B	8
10.	D	8
11.	D	10
12.	C	12
13.	B	12
14.	D	6
15.	A	6

TRUE OR FALSE

QUESTION #	ANSWER	REFERENCE PAGE
1.	F	4
2.	F	5
3.	T	11
4.	T	9
5.	F	11
6.	T	11
7.	F	4
8.	T	4
9.	T	12
10.	F	4

APPENDIX A

TEST # 2

MULTIPLE CHOICE

1. Why is low level wind shear considered the most dangerous type wind shear?

A. Because the shear at low levels is usually so violent that aircraft recovery is impossible.

B. Because it is most likely to affect the aircraft in a vulnerable condition of high-drag and low airspeed.

C. Because shear at low levels will have more turbulence associated with it.

D. Because thunderstorms are more likely to cause low level wind shear.

2. How does a LLWS-caused change in relative airflow over an aircraft's wings affect the aircraft's performance?

A. It reduces the aircraft's acceleration capabilities.

B. The aircraft's performance is reduced because lift is reduced.

C. The aircraft's performance is either reduced or increased because lift is either increased or decreased.

D. LLWS does not affect the relative airflow of wind over an aircraft's wings.

3. All of the following, except one, are factors that have a bearing on the effects of wind shear.

A. Ability of the flight crew to respond.

B. Aircraft speed and engine response.

C. Aircraft aerodynamic characteristics and aircraft configuration.

D. Amount of rain present in the wind shear.

4. For which type aircraft is the greatest hazard of LLWS likely to be on takeoff, instead of during an approach?

A. Both large and small aircraft.

B. Only small under-powered aircraft

C. Only large aircraft.

D. Heavy aircraft and ones that take time to accelerate to their best climb speed.

5. Which of the general type classes of LLWS is considered the most dangerous?

A. Thunderstorms.

B. Horizontal shears.

C. Low level inversions.

D. Vertical shears.

6. In which area/areas of a thunderstorm can LLWS be present?

A. On all sides of the thunderstorm..

B. Only on the side of the thunderstorm where downdrafts are present.

C. Only in the first gusts area of the thunderstorm..

D. In any area of the thunderstorm where strong winds are present.

7. What phenomena in high based cumulus clouds produces LLWS?

A. The combination of rain chilling and evaporation cooling of downdrafts.

B. The first gust phenomena.

C. Strong surface winds in conjunction with turbulence.

D. Cool surface temperatures and wet surface air.

8. Which of the following in not true concerning LLWS associated with fronts?

A. All fronts have associated wind shear.

B. Both warm and cold fronts can cause LLWS.

C. Warm fronts usually produce the most dangerous LLWS.

D. LLWS associated with cold fronts usually occurs after frontal passage at the airfield.

9. LLWS associated with land/sea breezes is caused by which of the following?

A. Heating of the land and sea surfaces.

B. Turbulence found in the cool air coming from the sea which encounters warm air from the land.

C. Differential heating or cooling of the land and sea surfaces.

D. Breezes coming off the sea are accelerated by the rise in terrain as it passes over the land mass.

10. ______ is a doppler radar system that will improve the recognition of wind shear, gust-fronts, downbursts, and other potentially hazardous weather conditions.

A. LLWSAS

B. NEXRAD.

C. JAWS.

D. NCAR.

11. Why is the current FAA LLWSAS considered inadequate to detect and warn of microburst occurrence?

A. Because the present LLWSAS system is not installed at all airports that could experience LLWS.

B. Because only airborne detection systems can do the job.

C. Because microbursts are smaller than the LLWSAS detection scale.

D. Because microbursts are larger than the LLWSAS detection scale.

12. The infrared(IR) band radiometer has been used to successfully detect LLWS from an airborne platform by:

A. measuring the drop in temperature from the ambient non-sheared environment to the sheared environment.

B. measuring the difference in wind speed between the shear and non-shear area with CO2 molecular spectrum device.

C. a shaped mosaic of detectors utilizing a common optical system thus providing the pilot with avoidance alternatives.

D. measuring the moisture differential between the shear and non-shear area.

13. Which of the following airspeeds is considered the most reliable indication to the pilot when experiencing LLWS?

A. Indicated airspeed.

B. MACH indicator.

C. Ground speed.

D. True airspeed.

14. Which is the correct aircraft reaction to a horizontal shear which is an increasing headwind?

A. IAS increases, lift decreases, and the aircraft pitchs up.

B. IAS and lift increases, and the aircraft pitchs down.

C. IAS decreases, lift increases, and the aircraft pitchs up.

D. Indicated airspeed increases, lift increases, and the aircraft pitchs up.

15. Which general type of wind shear is a pilot most likely to encounter?

A. Microbursts.

B. Fronts.

C. Land/sea breezes.

D. Horizontal wind shears.

TRUE OR FALSE QUESTIONS

Circle the most correct answer of the following questions.

T F 1. Of the two types of horizontal wind shears, only the decreasing headwind is a decreasing performance situation.

T F 2. When faced with a LLWS encounter, loss of airspeed is more important than flight path control.

T F 3. Probably the best indication to the pilot that the aircraft is encountering LLWS in on the aircraft instruments.

T F 4. Pilots should not be responsible for LLWS avoidance because of its insidiousness.

T F 5. There has been little progress in airborne equipment development which will detect LLWS.

T F 6. Any time a radiational inversion is present, the possibility of LLWS exists.

T F 7. The probability of getting grabbed by a microburst is high, but the consequences if you do are low.

T F 8. Microbursts have only recently been identified - during the mid-1970s.

T F 9. The only real difference between macrobursts and microbursts is their size and duration.

T F 10. LLWS is shear occurring between the surface and 1,500 feet AGL.

ANSWERS TO EXAMINATIONS

EXAM # 2

MULTIPLE CHOICE:

QUESTION #	ANSWER	REFERENCE PAGE
1.	B	3
2.	C	3
3.	D	3
4.	D	4
5.	D	5
6.	A	6
7.	A	7
8.	A	12
9.	C	13
10.	B	17
11.	C	19
12.	A	20
13.	C	32
14.	D	34
15.	D	33

TRUE OR FALSE

QUESTION #	ANSWER	REFERENCE PAGE
1.	T	36
2.	F	31
3.	T	25
4.	F	28
5.	F	22
6.	T	15
7.	F	12
8.	F	9
9.	T	8
10.	F	3

APPENDIX

APPENDIX B

HANDBOOK

ON

RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR HAZARDS

93BMW/SIFC

CASTLE AFB, CA

APPENDIX B

EFFECTS OF LOW LEVEL WIND SHEAR

1. DEFINITIONS:

*WIND SHEAR: "Wind shear" is a change in wind speed and/or direction over a short distance, which results in a tearing or shearing action. The term "wind shear" refers to the shearing or scissor-like action of two air masses moving in relation to one another.

*LOW LEVEL WIND SHEAR(LLWS): "Low level wind shear" is shear occurring between the surface and 2,000 feet AGL, where the greatest accident potential for takeoff and landing exist.

2. TWO GENERAL CLASSES OF WIND SHEARS:

*HORIZONTAL: Horizontal wind shears are present just about everywhere, but they are not as dangerous as vertical wind shears because the velccities and rates of change are smaller. These small changes usually permit pilots and airplanes to adjust safely and in a timely manner. The effects of horizontal wind shears are sudden changes in rate of climb or descent, or in position with respect to the glideslope, and are always accompanied by changes in airspeed.

*VERTICAL: Vertical shears are more serious and only recently discovered(1975). They occur mostly around thunderstorms and fronts. Sudden changes in rate of climb or descent caused by vertical wind shears is not accompanied by changes in airspeed, only angle of attack and vertical velocity change.

3. FACTORS HAVING A BEARING ON THE EFFECTS OF LLWS:

*AIRCRAFT CONFIGURATION: Aircraft configuration for takeoff and landing usually includes gear and flaps. This high drag, low-airspeed condition makes the aircraft very vulnerable to LLWS hazards.

*AIRCRAFT SPEED: In general, the higher the airspeed for a given configuration, the less LLWS will affect the aircraft's flight path. However, attitude often must also be increased to take advantage of the increased airspeed.

*AERODYNAMIC CHARACTERISTICS: In general, the more swept back the wings of an aircraft, the less effective the wings are at producing lift when at slow airspeeds.

*POWER/WEIGHT RATIO: Obviously, the greater the power to weight ratio an aircraft has the faster it will accelerate which is an aid in recovery from severe LLWS.

*ENGINE RESPONSE: High performance, jet aircraft have many advantages over slower propeller aircraft. However, one disadvantage of jet aircraft is longer spool up time for acceleration. This is especially true of heavy, wide-bodied aircraft.

*FLIGHT CREW RESPONSE: When experiencing LLWS the crew must first detect the dangerous situation and then make the proper response. Both these required events take time. Unfortunately, time may not be available when near the ground.

APPENDIX B

CAUSES OF LOW LEVEL WIND SHEAR HAZARDS

1. THUNDERSTORMS: Wind shear hazards associated with thunderstorms are the most hazardous due to the severity, complexity, and multiplicity of the shears produced.

*CAUSATION CATEGORIES: LLWS hazards associated with thunderstorms can be grouped into four categories based on size, duration, and effects.

**HIGH-BASED CUMULUS CLOUDS: High-based innocuous-appearing, cumulus clouds can be the root of severe wind shear. LLWS can be expected under high-based cumulus clouds when: Virga is present; surface air is very dry with dew point spread of 35 degrees F or more; surface winds are weak, less than 15 knots; and surface temperature is warmer than 75 degrees F.

**FIRST GUSTS: The first gust is a rapid shift and increase in wind just before a thunderstorm hits - up to 15 miles ahead of storm.

**LARGE DOWNBURSTS OR "MACROBURSTS": The downburst is an extremely intense localized downdraft from a thunderstorm. The macroburst ranges in width from 2.6 NM to 12.5NM and in duration from five to 20 minutes.

**"MICROBURSTS": Its the intensity, compactness, and short-lived nature of microbursts that make them so insidiously dangerous(most dangerous of all hazards). Microbursts are .25 to 2.5 NM in diameter and two to ten minutes in duration.

2. FRONTS: After thunderstorms, certain frontal systems are the most prominent cause of significant LLWS hazards. Both warm and cold fronts cause significant wind shears.

*WARM FRONTS: Wind shear associated with a warm front is more dangerous than cold front wind shear because warm front winds are more severe and low visibilities are usually also present. LLWS usually reaches the airfield six to 12 hours before warm frontal passage.

*COLD FRONTS: LLWS hazards associated with a cold front are usually less dangerous because normally the danger area is of shorter duration and no low visibilities accompany the maximum winds. LLWS will occur 30 minutes to one hour after cold frontal passage at the surface.

3. LAND/SEA BREEZE PHENOMENON: Differential heating and cooling of land and sea surfaces can cause severe LLWS. The sea breeze is a small scale frontal boundary and reaches its maximum penetration in mid to late afternoon. Land breezes occur at night because the land becomes cooler than the water.

4. MOUNTAIN WAVES OR FUNNELING WINDS: Wind passing over or by rising terrain is accelerated and can cause severe LLWS when it spills into an aircraft's flight path.

5. LOW LEVEL JETS OVER RADIATION INVERSIONS: Overnight cooling of land can create a temperature inversion a few hundred feet above the ground. This, coupled with high winds from what is know as the low level jet, can produce significant LLWS.

APPENDIX B

RECOGNITION AND DETECTION OF LLWS

1. MAGNITUDE OF THE DETECTION PROBLEM: Weather radar had to be modified to detect wind shear(NEXRAD). Wind shear can not be seen, and a large volume of air must be searched if all major airports are to be protected.

2. RESEARCH FOR POSSIBLE SOLUTIONS TO WIND SHEAR DETECTION: Investigation of a 1975 accident of a Boeing 727 at Kennedy Airport led to the conclusion that it had encountered vertical gusts so powerful that it could not climb through them to remain on the glideslope. The idea of vertical gusts so intense that recovery was not possible led to many Government sponsored studies.

*JOINT AIRPORT WEATHER STUDIES(JAWS): A $2.2 million dollar, three-year project conducted by the National Center for Atmospheric Research and the University of Chicago with principal funding from the National Science Foundation. The principle objectives of JAWS was to acquire additional basic knowledge on microbursts and their environment to help scientist understand what causes them and how they can be detected and predicted.

*HEARING BEFORE U.S. CONGRESS(HOUSE) COMMITTEE ON SCIENCE & TECHNOLOGY: Hearing was mandated by U.S. Congress to address the need for improvement of wind shear detection methods.

3. AREAS OF POSSIBLE SOLUTIONS RESULTING FROM RESEARCH:

*FORECASTING AND PREDICTION IMPROVEMENTS: Studies called for the development of the Next-Generation Weather Radar System(NEXRAD). The NEXRAD is a doppler radar system that will improve the recognition of wind shear, gust fronts, downbursts, and other potentially hazardous weather conditions.

*<u>GROUND-BASED SENSORS</u>: Many airports have ground detectors known as Low Level Wind Shear Alert Systems(LLWSAS). The LLWSAS consists of an array of wind sensors distributed about the airport and connected to a central processor that sounds an alarm to the tower whenever the wind vectors at two sensors differ by 15 knots or more.

*<u>AIRBORNE DETECTION DEVICES</u>: Airborne flight simulations to evaluate airborne devices for the detection and display of wind shear information in the cockpit have been conducted for transport category aircraft over the past several years. Both lidar radar and infrared(IR) forward-looking thermal radiometer detectors were successful in detecting the presence of wind shear by measuring temperature differentials. However, the research done thus far has been able to only give limited warning times and distances. Current research is continuing with the hope of giving from 3 to 7 NM warning of impending LLWS.

4. <u>STATUS OF USAF ON STATE-OF-THE-ART DETECTION EQUIPMENT</u>: Today, the Air Force does not have the equipment for continuous, accurate measurement or detection of LLWS in the vicinity of its airfields. The Air Force has proposed the development of a Low Altitude Wind Warning System(LAWWS). The approval, funding and development of the proposed LAWWS have not yet been completed, but positive action is being taken to provide an operational system in the future.

5. <u>INFORMATION SOURCES FOR LLWS</u>: There are numerous information sources available for LLWS detection.

*PREFLIGHT WEATHER FORECASTS: The best way to anticipate LLWS for departure or at your destination is from the preflight weather briefing. Don't hesitate to ask the forecaster about the possibilities of LLWS.

*PIREPS: PIREPS are a major source of weather information; they provide real-time data to the weather forecaster. When you call in for your landing weather be sure to ask if any LLWS has been reported.

*PMSV AND AIR TRAFFIC CONTROL: These are excellent sources to keep you updated on both the latest weather information and the latest PIREPS.

*AIRCRAFT INSTRUMENTS: Pilots flying aircraft with ground speed readouts should compare the winds at the initial approach altitude with reported runway surface winds to see if LLWS is likely. For aircraft without ground speed readouts, monitoring aircraft performance can reveal the presence of LLWS. By observing the aircraft's approach parameters, the pilot can determine if LLWS is present.

HOW TO CONTROL AND COPE WITH LLWS

1. ULTIMATE RESPONSIBILITY FOR SAFETY RESTS WITH PILOT: There is no question crews are better equipped to deal with LLWS now than at any time in the past, thanks to new technology. However, the ultimate responsibility for safety of flight must still be based on pilot or aircrew judgment.

2. DIFFERENT TECHNIQUES FOR DIFFERENT TYPES OF WIND SHEAR: Crew response to LLWS depends on whether the wind shear is a vertical or horizontal shear.

APPENDIX B

*<u>VERTICAL WIND SHEAR("MICROBURSTS")</u>: An encounter with a vertical wind shear is less likely, but extremely dangerous. There are two schools of thought on how to optimize aircraft performance during an encounter with a vertical shear. One technique involves flying out at the minimum drag speed, while the second is called the "stick shaker" method.

**<u>FLYING AT MINIMUM DRAG SPEED</u>: Many pilots have been trained to lower the nose to pick up airspeed when it is falling off. In a LLWS situation, this could be fatal. You have traded too much potential energy for kinetic energy. When encountering microburst conditions near the ground, lowering the nose of your aircraft results in a further, more critical reduction in AOA, a significant loss of altitude, a degradation in climb performance, and probably ground impact.

**<u>"STICK SHAKER" METHOD</u>: A more favorable alternative would be to apply maximum thrust while smoothly increasing pitch attitude until the descent is arrested or a stick shaker condition is reached.

*<u>HORIZONTAL WIND SHEAR</u>: The horizontal wind shear is more frequent, but less dangerous. This type shear is usually more gradual and the pilot and aircraft have more time to make adjustments. Horizontal shears fit into two categories: increasing headwinds; and decreasing headwinds.

APPENDIX B

**INCREASING HEADWIND: Performance increasing situation is created here.

***TAKEOFF PROCEDURES: Takeoff into an increasing headwind shear is no problem as performance is increasing.

***LANDING PROCEDURES:

****Do not pad approach speed. If shear exists, indicated airspeed and lift will increase.

****If shear is close to the ground(past decision height), it might cause a long, hot landing. Go around, if unable to land in touchdown zone.

****If shear is encountered at a higher altitude, resist the temptation to make a large power reduction. Accept higher indicated airspeed and use pitch and trim to get back to glide path, if possible. But avoid large trim changes.

****Avoid high descent rates with the engines spooled down. If you can't restabilize on glide path, go around.

**DECREASING HEADWIND: Decreasing performance situation exists here, as ground speed is lower than reference ground speed.

APPENDIX B

***<u>TAKEOFF PROCEDURES</u>:

****Delay takeoff, if possible.

****Pad rotate and climbout airspeeds, runway and obstacles permitting.

****If unable to delay takeoff, let airspeed build as soon as possible after takeoff and delay flap retraction until the upper limits of the flap retraction schedule.

***<u>LANDING PROCEDURES</u>:

****Pad approach airspeed by the amount of the shear potential.

****Be aware of stopping distance. This should rarely be a limiting factor, considering the length of SAC runways and normal landing gross weights. However, watch with low RCRs.

****Monitor ground speed. If it increases gradually(no shear exists), then anticipate the need to reduce power and increase descent rate in the final part of the approach.

****Avoid high descent rates with engines spooled down.

****If a go around is necessary, use full thrust. Don't be shy!

3. REFERENCE GROUND SPEED: Using ground speed as a reference during an approach when LLWS is suspected is important because it insures flying airspeed at all times, even in abrupt wind shear situations. Ground speed as a parameter is a radical departure from the school of thought that says a stabilized and constant indicated airspeed with very small power changes will result in the best precision approach.

APPENDIX

APPENDIX C

SOUND-ON-SLIDE SCRIPT

ON

RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR HAZARDS

93BMW/SIFC

CASTLE AFB, CA

APPENDIX C

SOUND-ON-SLIDE SCRIPT

SLIDE 1 (TITLE OF COURSE)

RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR HAZARDS

SLIDE 2 (WHY STUDY LLWS?)

From 1962 to 1982, there were 127 U.S. Air Carrier accidents in which thunderstorms/LLWS hazards were found to be either a cause or a factor. These accidents cost 545 lives and 260 injuries. From 1965 to 1974, the USAF experienced 41 probable wind shear/vortex related aircraft accidents - the total price tag was $18 million dollars.

SLIDE 3 (OUTLINE OF COURSE)

I. EFFECTS OF LOW LEVEL WIND SHEAR

II. CAUSES OF LOW LEVEL WIND SHEAR

III. RECOGNITION AND DETECTION OF LOW LEVEL WIND SHEAR

IV. HOW TO CONTROL AND COPE WITH LOW LEVEL WIND SHEAR

SLIDE 4 (EFFECTS OF LOW LEVEL WIND SHEAR)

I. DEFINITIONS

II. CLASSES OF WIND SHEAR

III. FACTORS HAVING A BEARING ON EFFECTS OF LLWS

SLIDE 5 (DEFINITION OF WIND SHEAR)

Wind shear is a change in wind speed and/or direction over a short distance, which results in a tearing or shearing action. The term "wind shear" refers to the shearing or scissor-like action of two air masses moving in relation to one another.

SLIDE 6 (DEFINITION OF LOW LEVEL WIND SHEAR)

"Low level wind shear" is shear occurring between the surface and 2,000 feet AGL, where the greatest accident potential for takeoff and landing exist.

SLIDE 7 (TWO GENERAL CLASSES OF WIND SHEAR)

*HORIZONTAL SHEAR

*VERTICAL SHEAR

SLIDE 8 (HORIZONTAL SHEARS)

Horizontal wind shears are present just about everywhere, but they are not as dangerous as vertical shears because the velocities and rates of change are smaller. These small changes usually permit pilots and airplanes to adjust safely and in a timely manner. The effects of horizontal wind shears are sudden changes in rate of climb or descent, or in position with respect to the glideslope, and are always accompanied by changes in indicated/ground speed.

SLIDE 9 (VERTICAL SHEARS)

Vertical shears are more serious and only recently have been discovered(1975). They occur mostly around thunderstorms and fronts. Sudden changes in rate of climb or descent caused by vertical wind shears is not accompanied by changes in airspeed, only angle of attack and vertical velocity change.

SLIDE 10 (FACTORS HAVING A BEARING ON THE EFFECTS OF LLWS)

1. AIRCRAFT CONFIGURATION
2. AIRCRAFT SPEED
3. AERODYNAMIC CHARACTERISTICS
4. POWER/WEIGHT RATIO
5. ENGINE RESPONSE
6. FLIGHT CREW RESPONSE

SLIDE 11 (AIRCRAFT CONFIGURATION)

Aircraft configuration for takeoff and landing usually includes gear and flaps. This high drag, low-airspeed condition makes the aircraft very vulnerable to LLWS hazards and inhibits acceleration.

APPENDIX C

SLIDE 12 (AIRCRAFT SPEED)

In general, the higher the airspeed for a given configuration, the less LLWS will affect the aircraft's flight path - assuming proper corrective actions are taken.

SLIDE 13 (AERODYNAMIC CHARACTERISTICS)

In general, the more swept back the wings of an aircraft, the less effective the wings are at producing lift when at slow airspeeds. Also drag affects acceleration rates.

SLIDE 14 (POWER/WEIGHT RATIO)

Obviously, the greater the power to weight ratio of an aircraft, the faster it will accelerate which is an aid in recovery from severe LLWS.

SLIDE 15 (ENGINE RESPONSE)

High performance, jet aircraft have many advantages over slower propeller aircraft. However, one disadvantage of jet aircraft is longer spool up time for acceleration. This is especially true of heavy, wide-bodied jet aircraft.

SLIDE 16 (FLIGHT CREW RESPONSE)

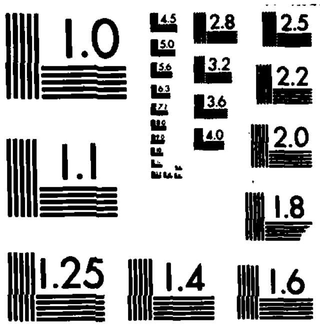
This is the most important factor. When experiencing LLWS the crew must first detect the dangerous situation and then make the proper response. Both these required events take time. Unfortunately, time may not be available when near the ground.

AD-A156 500 RECOGNITION AND CONTROL OF LOW LEVEL WIND SHEAR(U) AIR COMMAND AND STAFF COLL MAXWELL AFB AL W G ROGERS APR 85 ACSC-85-2215 2/2

UNCLASSIFIED F/G 4/2 NL

END

8-85



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SLIDE 17 (CAUSES OF LLWS)

1. THUNDERSTORMS
2. FRONTS
3. LAND/SEA BREEZES
4. MOUNTAIN WAVES OR FUNNELING WINDS
5. LOW LEVEL JETS OVER RADIATION INVERSIONS

SLIDE 18 (THUNDERSTORMS)

Wind shear hazards associated with thunderstorms are the most hazardous due to the severity, complexity, and multiplicity of the shears produced.

SLIDE 19 (THUNDERSTORM CAUSATION CATEGORIES)

LLWS hazards associated with thunderstorms can be grouped into four categories based on size, duration, and effects.

1. HIGH-BASED CUMULUS CLOUDS
2. FIRST GUSTS
3. LARGE DOWNBURSTS OR "MACROBURSTS"
4. SMALL DOWNBURSTS OR "MICROBURSTS"

SLIDE 20 (HIGH-BASED CUMULUS CLOUDS)

High-based, innocuous-appearing cumulus clouds can be the root of severe wind shear. LLWS can be expected under high -based, cumulus clouds when: Virga is present; surface air is very dry with dew point spread of 35 degrees F or more; surface winds are weak, less than 15 knots; and surface temperature is warmer than 75 degrees F.

SLIDE 21 (FIRST GUSTS)

The first gust is a rapid shift and increase in wind just before a thunderstorm hits - up to 15 miles ahead.

SLIDE 22 (LARGE DOWNBURSTS OR "MACROBURSTS")

The downburst is an extremely intense localized downdraft from a thunderstorm. The "macroburst" ranges in width from 2.6 NM to 12.5 NM and in duration from five to 20 minutes.

SLIDE 23 ("MICROBURSTS")

Its the intensity, compactness, and short-lived nature of microbursts that make them so insidiously dangerous. They are the most dangerous of all hazards. Microbursts are .25 to 2.5 NM in diameter and two to ten minutes in duration.

SLIDE 24 (FRONTS - WARM AND COLD)

After thunderstorms, certain frontal systems are the most prominent cause of significant LLWS hazards. Both warm and cold fronts cause significant wind shears.

SLIDE 25 (WARM FRONTS)

Wind shear associated with a warm front is more dangerous than a cold front wind shear because warm front winds are more severe and low visibilities are usually present. LLWS usually reaches the airfield six to 12 hours before warm frontal passage.

SLIDE 26 (COLD FRONTS)

LLWS hazards associated with a cold front are usually less dangerous because normally the danger area is of shorter duration and no low visibilities are present. LLWS will occur 30 minutes to one hour after cold frontal passage at the surface.

SLIDE 27 (LAND/SEA BREEZE PHENOMENA)

Differential heating and cooling of land and sea surfaces can cause LLWS. The sea breeze is a small scale frontal boundary and reaches its maximum penetration in mid to late afternoon. Land breezes occur at night because the land becomes cooler than the water.

SLIDE 28 (MOUNTAIN WAVES OR FUNNELING WINDS)

Wind passing over or by rising terrain is accelerated and can cause wind shear when it spills into an aircraft's flight path.

SLIDE 29 (LOW LEVEL JETS OVER RADIATION INVERSIONS)

Overnight cooling of land can create a temperature inversion a few hundred feet above the ground. This, coupled with high winds from what is known as the low level jet, can produce significant wind shears near the ground.

APPENDIX C

SLIDE 30 (RECOGNITION AND DETECTION OF LLWS)

1. MAGNITUDE OF THE DETECTION PROBLEM

2. RESEARCH FOR SOLUTIONS TO LLWS DETECTION PROBLEM

3. SOLUTION AREAS RESULTING FROM RESEARCH

4. STATUS OF USAF ON STATE-OF-THE ART DETECTION EQUIPMENT

5. INFORMATION SOURCES FOR LLWS

SLIDE 31 (MAGNITUDE OF DETECTION PROBLEM)

Weather radar had to be modified to detect wind shear(NEXRAD). Wind shear can not be seen, and a large volume of air must be searched if all major airports are to be protected.

SLIDE 32 (RESEARCH FOR SOLUTIONS TO DETECTION PROBLEM)

1. JOINT AIRPORT WEATHER STUDIES(JAWS)

2. CONGRESSIONAL HEARING

Investigation of a 1975 accident of a Boeing 727 at Kennedy Airport led to the conclusion that it had encountered vertical gusts which caused the crash. The idea of vertical gusts so powerful that recovery was not possible led to many Government sponsored studies.

SLIDE 33 (JAWS)

A $2.2 million dollar, three-year project conducted by the National Center for Atmospheric Research and the University of Chicago with principal funding from the National Science Foundation. The principal objectives of JAWS was to acquire additional basic knowledge on microbursts and their environment to help scientist understand what causes them and how they can be detected and predicted.

SLIDE 34 (CONGRESSIONAL HEARING ON LLWS)

Hearing was mandated by US Congress to address the need for improvement of wind shear detection methods and equipment.

SLIDE 35 (POSSIBLE SOLUTIONS RESULTING FROM RESEARCH)

1. FORECASTING AND PREDICTION IMPROVEMENTS
2. GROUND-BASED SENSORS
3. AIRBORNE DETECTION DEVICES

SLIDE 36 (FORECASTING AND PREDICTION IMPROVEMENTS)

Studies called for the development of the Next-Generation Weather Radar(NEXRAD). The NEXRAD is a doppler radar system that will improve the recognition of wind shear, gust-fronts, downbursts, and other potentially hazardous weather conditions.

SLIDE 37 (GROUND-BASED SENSORS)

Many airports have ground detectors known as Low Level Wind Shear Alert Systems(LLWSAS). The LLWSAS consists of an array of wind sensors distributed about the airport and connected to a central processor that sounds as alarm to the tower whenever the wind vectors at two sensors differ by 15 knots or more.

SLIDE 38 (AIRBORNE DETECTION DEVICES)

Airborne flight simulations to evaluate airborne devices for the detection and display of wind shear information in the cockpit have been conducted for transport category aircraft over the past several years. Both lidar radar and infrared(IR) forward-looking thermal radiometer detectors were successful in detecting the presence of wind shear up to three miles in front of the test aircraft.

SLIDE 39 (STATUS OF USAF ON STATE-OF-THE ART DETECTION EQUIPMENT)

Today, the Air Force does not have the equipment for continuous, accurate measurement or detection of LLWS in the vicinity of our bases. The Air Force has proposed the development of a Low Altitude Wind Warning System(LAWWS). The approval, funding and development of the proposed LAWWS have not yet been completed, but positive action is being taken to provide an operational system in the future.

SLIDE 40 (INFORMATION SOURCES FOR LLWS)

There are numerous information sources available for LLWS detection:

1. PREFLIGHT WEATHER FORECASTS

2. PIREPS

3. PMSV AND AIR TRAFFIC CONTROL

4. AIRCRAFT INSTRUMENTS

SLIDE 41 (PREFLIGHT WEATHER FORECASTS)

The best way to anticipate LLWS for departure or at your destination is from the preflight weather briefing. Don't hesitate to ask the forecaster about the possibilities of LLWS.

SLIDE 42 (PIREPS)

PIREPS are a major source of weather information; they provide real-time data to the weather forecaster. When you call in for your landing weather be sure to ask if any LLWS has been reported.

SLIDE 43 (PMSV AND AIR TRAFFIC CONTROL)

These are excellent sources to keep you updated on both the latest weather information and the latest PIREPS.

SLIDE 44 (AIRCRAFT INSTRUMENTS)

Pilots flying aircraft with ground speed readouts should compare the winds at the initial approach altitude with reported runway surface winds to see if LLWS is present. For aircraft without ground speed readouts, monitoring aircraft performance can reveal LLWS. By observing the aircraft's approach parameters, the pilot can determine if LLWS is present.

APPENDIX C

SLIDE 45 (HOW TO COPE WITH LLWS)

1. ULTIMATE RESPONSIBILITY FOR SAFETY RESTS WITH PILOT

2. DIFFERENT TECHNIQUES FOR DIFFERENT TYPES OF LLWS

3. REFERENCE GROUNDSPEED

SLIDE 46 (PILOT HAS ULTIMATE RESPONSIBILITY)

There is no question crews are better equipped to deal with LLWS now than at any time in the past, thanks to new technology. However, the ultimate responsibility for safety of flight must still be based on pilot judgment.

SLIDE 47 (DIFFERENT TECHNIQUES FOR DIFFERENT TYPE LLWS)

Crew response to LLWS depends on whether the wind shear is a vertical or horizontal shear.

1. VERTICAL WIND SHEAR

2. HORIZONTAL WIND SHEAR

SLIDE 48 (VERTICAL WIND SHEAR - "MICROBURSTS")

An encounter with a vertical wind shear is less likely, but extremely dangerous. There are two schools of thought on how to optimize aircraft performance during an encounter with a vertical shear. One technique involves flying out at the minimum drag speed, while the second is called the "stick shaker" method.

1. FLYING AT MINIMUM DRAG SPEED

2. STICK SHAKER SPEED

SLIDE 49 (FLYING AT MINIMUM DRAG SPEED)

Many pilots have been trained to lower the nose to pick up airspeed when it is falling off. In a LLWS situation, this could be fatal. You have traded too much potential energy for kinetic energy. When encountering microburst conditions near the ground, lowering the nose of your aircraft results in a further, more critical reduction in AOA, a significant loss of altitude, a degradation in climb performance and ground impact.

SLIDE 50 (STICK SHAKER METHOD)

A more favorable alternative would be to apply maximum thrust while smoothly increasing pitch attitude until the descent is arrested or a stick shaker condition is reached.

SLIDE 51 (HORIZONTAL WIND SHEAR)

The horizontal wind shear is more frequent, but less dangerous. This type shear is usually more gradual and the pilot and aircraft have more time to make adjustments. Horizontal shears fit into two categories: increasing headwinds; and decreasing headwinds.

1. INCREASING HEADWIND
2. DECREASING HEADWIND
3. REFERENCE GROUNDSPEED

SLIDE 52 (INCREASING HEADWIND)

Performance increasing situation is created here.

1. TAKEOFF PROCEDURES
2. LANDING PROCEDURES

SLIDE 53 (TAKEOFF PROCEDURES)

Takeoff into an increasing headwind shear is no problem as performance is increasing.

SLIDE 54 (LANDING PROCEDURES)

1. Do not pad approach speed. If shear exists, indicated airspeed and lift increase.

2. If shear is close to the ground(past decision height), it might cause a long, hot landing. Go around, if unable to land in touchdown zone.

3. If shear is encountered at a higher altitude, resist the temptation to make a large power reduction. Accept higher indicated airspeed and use pitch and trim to get back to glide path, if possible. But avoid large trim changes.

4. Avoid high descent rates with engines spooled down; and if you can't restabilize on glide path - go around.

SLIDE 55 (DECREASING HEADWIND)

Decreasing performance results here as ground speed is lower than reference ground speed.

1. TAKEOFF PROCEDURES
2. LANDING PROCEDURES

APPENDIX C

SLIDE 56 (TAKEOFF PROCEDURES)

1. Delay takeoff, if possible.

2. Pad rotate and climbout airspeeds by shear amount, if runway and obstacles permit.

3. If unable to delay takeoff, let airspeed build as soon as possible after takeoff, and delay flap retraction until the upper limits of the flap retraction schedule.

SLIDE 57 (LANDING PROCEDURES)

1. Pad approach airspeed by the amount of shear potential.

2. Be aware of stopping distance. This should rarely be a limiting factor, considering length of SAC runways and normal landing weights.(However, watch low RCRs).

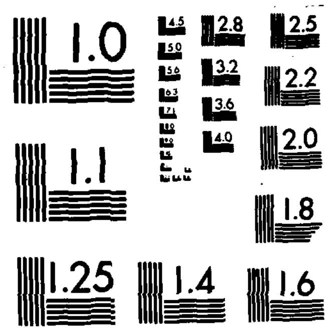
3. Monitor ground speed. If it increases gradually(indicates no shear exists), then anticipate the need to reduce power and increase descent rate in the final part of the approach.

4. Avoid high descent rates with engines spooled down.

5. If a go around is necessary, use full thrust. Simulator tests show pilots usually add less power than they think they did. Don't be shy.

<u>SLIDE 58</u> (REFERENCE GROUND SPEED)

Using ground speed as a reference during an approach when LLWS is suspected is important because it insures flying airspeed at all times, even in abrupt wind shear situations. Ground speed as a parameter is a radical departure from the school of thought that says a stabilized and constant indicated airspeed with very small power changes will result in the best precision approach.



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A